JUL 14 1930

Volume XII MAY, 1930 Number 5

THE JOURNAL OF INDUSTRIAL HYGIENE

WITH ABSTRACT OF THE LITERATURE

Editor, United States
DAVID L. EDSALL, M.D., S.D.

Honorary Consulting Editor
SIR THOMAS M. LEGGE, M.D., D.P.H.

Editor, Great Britain
E. L. COLLIS, M.D., M.R.C.S.

Occupational Cancers

The Occurrence of Pulmonary Fibrosis and Other Pulmonary Affections in Asbestos Workers

Published at Mount Royal and Guilford Aves., Baltimore, Md.
by HARVARD SCHOOL OF PUBLIC HEALTH

Entered as second-class matter, at the Post Office at Baltimore, Maryland, under Act of March 3, 1879.
Copyright, 1930, by Harvard Medical School

Made in the United States of America

EDITORS

United States

DAVID L. EDSALL, M.D., S.D.

Great Britain

E. L. COLLIS, M.D., M.R.C.S.

HONORARY CONSULTING EDITOR

SIR THOMAS M. LEGGE, M.D., D.P.H.

ASSOCIATE EDITORS

United States

W. IRVING CLARK, JR., M.D.

LELAND E. COFER, M.D.

ALICE HAMILTON, A.M., M.D.

EMERY R. HAYHURST, A.M., Ph.D., M.D.

YANDELL HENDERSON, Ph.D.

HARRY E. MOCK, M.D.

L. R. THOMPSON, M.D.

C.-E. A. WINSLOW, M.S., A.M., Dr.P.H.

WILLIAM P. YANT, B.S.

Great Britain

W. F. DEARDEN, M.R.C.S., D.P.H.

SIR KENNETH GOADBY, K.B.E., M.R.C.S., D.P.H.

LEONARD HILL, M.B., F.R.S.

T. LISTER LLEWELLYN, B.S., M.D., M.I.M.E.

SIR THOMAS OLIVER, M.D.

R. PROSSER WHITE, M.D., M.R.C.S.

H. M. VERNON, A.M., M.D.

D. A. COLES, M.D.

South Africa

E. H. CLUVER, A.M., M.D., B.Ch., D.P.H.

Canada

J. J. R. MACLEOD, M.B.

MANAGING EDITORS

CECIL K. DRINKER, M.D.

PHILIP DRINKER, B.S., Ch.E.

MARION C. SHORLEY

THE JOURNAL OF INDUSTRIAL HYGIENE

VOLUME XII MAY, 1930 NUMBER 5

OCCUPATIONAL CANCERS*

IMRE HELLER, M.D., C.P.H.

CANCER CAUSED BY COAL TAR AND COAL TAR PRODUCTS

COAL tar is the product of the destructive distillation of coal. There are different kinds of coal tars, according to their chemical composition. The composition in turn is dependent on the kind of coal from which the tar is derived and on the method applied for carbonization. In this respect the most important factors are the temperature at which the destructive distillation is carried out and the length of time during which the coal is subjected to heat.

Kennaway (1) gives the classification of coal tars as follows:

1. Gas works tar from
   - Lightly and fully charged horizontal retorts
   - Inclined retorts
   - Intermittently and continuously charged vertical retorts
2. Blast furnace tar
3. Coke oven by-product tar
4. Producer gas tar

* Received for publication March 11, 1930.

Chemical Characteristics of Coal Tars in the United States

Gas works tar and coke oven tar are given particular consideration, as the kinds of tars which, as far as occupational cancer is concerned, are of the most importance.

Gas Works Tar (gas house tar, retort tar).—Bituminous coal is used for carbonization. Carbonization is carried out mostly in horizontal silica retorts. Periodically charged vertical retorts are used to a less extent. Both the horizontal and the vertical retort tars are high temperature tars; the temperature in the retorts goes up to 900 to 1,000°C. The time taken for carbonization is about six to eight hours.

In vertical retorts the length of time that the vapors distilled from the coal are in contact with the hot walls of the chamber is not the same as in the horizontal retorts (2). Both tars, however, contain almost the same constituents and the difference is shown in the varying proportions of the elements which make up the tar. Horizontal retort

tar contains more free carbon, less cresoloid and phenoloid bodies (tar acids), and yields more pitch than the vertical retort tar.

Inclined retorts are not used in the United States and the production of low temperature tar in continuously charged vertical retorts is only in the experimental stage (in the International Combustion Company, New Brunswick, N. J.).

In comparison with coke oven tar, gas works tar is characterized by the presence of aliphatic hydrocarbons (paraffins, naphthenes), and olefins in varying amount, depending on the temperature of production; furthermore, gas works tar contains more naphthalene, anthracene, and free carbon, and yields more pitch than does coke oven tar.

Coke Oven Tar.—Mostly high grade bituminous coal, from very different sources, is used for carbonization. Carbonization is carried out in Koppers and Vilputte ovens; the time of carbonization varies from twelve to sixteen hours. The coal is finally exposed to a high temperature ranging from 1,200 to 1,400°C. In the Koppers ovens the time of carbonization is longer, the temperature lower, and the quantity of by-products larger than in the Vilputte ovens.

Coke oven tar, having lower viscosity, is more fluid than gas works tar. It contains more ammoniacal liquor and oils, but the amount of tar acids is about the same as in the horizontal retort tars.

Producer Gas Tar.—Producer gas tar has a large percentage of water and free carbon, together with a small amount of oils, and yields, when distilled, a poor, friable pitch (3).

Blast Furnace Tar.—Blast furnace tar has the characteristics of low temperature tars. It contains aliphatic hydrocarbons (chiefly paraffins), and more phenoloid and basic substances than does gas works tar. Characteristic of blast furnace tar is the small content of benzene, naphthalene, and anthracene.

Attention must be paid to water gas tar, which is a by-product in manufacturing water gas for illumination. Water gas tar does not belong to the coal tar series; nevertheless it is often mixed with coal tars and it is one of the tars which are mostly used for distillation. Water gas is produced by forcing steam through incandescent coke, and the gas formed is sprayed with oil in chambers containing red hot bricks (carbureting). During the oil carbureting, some heavy vapors condense out of the gas on cooling. The condensate, known as water gas tar, is very fluid, containing a large amount of water. Paraffins are regularly present. It has no ammoniacal liquor, contains a very small amount of tar acids, and yields only a small quantity of pitch.

The valuable properties of tar and the possibility of wide application of its products for industrial purposes have increased the demand for coal tar and for its distillation products. The amount of coke and gas produced bears a direct relation to the output of coal tar. The largest output in the United States is in the form of coke oven tar, owing to the installation of by-product coke ovens for the production of a large quantity of coke and for supplying steel plants with fuel in the form of tar and pitch. The chief sources of gas production are the coke oven and

water gas plants, especially in larger cities. In New York City 70 per cent. of the tar produced is water gas; in Chicago, 75 per cent. is coke oven gas and 25 per cent. water gas; in Boston, the production of gas is partly water gas, partly coke oven gas.

Tar Distillation in the United States

The quantity and quality of tar distillation products vary greatly with the kind of tar used. In the United States, coke oven tar is mainly used for distillation, water gas tar is less used, and a comparatively small amount of gas house tar and producer gas tar is redistilled. According to Huff (4), coke oven tar compares very favorably with coal tars of other origins and is admirably adapted for distillation. In some cases different kinds of tars are mixed to meet certain specifications—for instance, roofing pitch is made from coke oven and gas works pitch; furthermore, the distillation process itself varies a great deal, according to the conditions of the market, and the demand for one or another distillation product. If creosote oil is required by the purchasers in a larger quantity, certain fractions are not recovered, but are included in the creosote oil. According to the requirements, certain products contain more or less of one or another constituent, and the distillation is carried out to meet the requisitions. Naturally, the chemical composition of the products varies a great deal. The greatest demand is for pitch and creosote oil, and other compounds are often not isolated, but are thrown on the market as constituents of pitch and creosote oil.

The following outline given by Huff (4) shows the fractions which are usually separated during the process of distillation in the United States.

	Per Cent.[1]
1. From atmospheric temperatures to 170°C.	
Products: light oil, water, some pyridine, some naphthalene (light oil fraction).	3.0
2. From 170°C. to 235°C.	
Products: crude phenol, cresylic acid, naphthalene (crude), pyridine, creosote oil (carbolic oil fraction) ...	12.2
3. From 235°C. to 270°C.	
Products: creosote oil, naphthalene (crude).....	12.3
4. From 270°C. to 315°C.	
Products: creosote oil, anthracene (crude).....	13.3
5. From 315°C. to 355°C. *supra*	
Products: creosote oil, anthracene (crude).....	9.8
Over 355°C. hard pitch is obtained.....	49.4

[1] Per cent. by volume referred to the original tar volume.

Usually the tar comes to the distillation plants in refined, dehydrated form. The raw tar has been subjected to heat, thereby extracting the water and ammonia, and the tar is sold in such refined form for distillation. If the tar is sold in unrefined form, it is heated up to 170°C. in the distillation plant. During this treatment, water and ammonia are separated from the tar, while the light oil, together with some naphthalene, is pumped to the light oil plants, where purification and recovery of benzene, xylene, etc., take place. However, very often light oil plants are operated in connection with by-product plants, and the tar is worked up in distillation plants after the light oil fraction has already been removed.

The condensate derived from the first fraction is subjected to further heating in various stills corresponding to the subsequent distillation fractions. The condensate of the second fraction (carbolic oil fraction) is conveyed to naphthalene crystallizing pans. The oil is drained off from the pans as completely as possible; the solid mass (naphthalene) crystallizes on cooling and is shoveled into centrifuges where the remaining oil is removed. The naphthalene either is sold in this stage as crude naphthalene containing certain impurities or goes to recrystallizing pans where its purification takes place. From the oil which is drained off, the tar acids are recovered, while the creosote oil content of this fraction is combined with the creosote oil of the next fraction. Tar acids consist mainly of phenol and the cresols; these are usually separated by using caustic soda solution (interchange process), and then by subjecting the phenolate or cresylate to carbon dioxide and treating it with sulphuric acid (decomposing process).

The fraction yielded between 235° and 270°C. contains naphthalene and creosote oil (dead oil). Naphthalene of this fraction is usually pumped into the creosote oil. What is commercially known as "creosote oil" is a material varying greatly in chemical character, being usually a mixture of several fractions. According to the requirements, naphthalene or tar acids are added in greater or less quantity, or are omitted during the distillation process. Some distilleries sell for wood preserving purposes creosote oil which contains practically all tar fractions up to pitch. Generally, the composition of the creosote oil depends upon the completeness of the distillation.

The fractions taken from 270°C. to 355° contain creosote oil and solid crude anthracene mixed with phenanthrene, carbazol, and many hydrocarbons. The oil is drained off. The remaining anthracene crystals still contain some oil, which is removed by filter presses. The resulting anthracene cake is recrystallized in order to separate it from other impurities (carbazol, phenanthrene, etc.). Anthracene is often not recovered, however, but is left either in the creosote oil or in the soft pitch.

Pitch is yielded at temperatures over 355°C., when a hard pitch is obtained. If medium or soft pitch is required, which is very often the case, the distillation is stopped at a lower temperature, when the pitch obtained contains the oils of the heavier fractions and consequently is softer. If the temperature in the still is not more than 280°C., soft pitch is produced; from 280° to 300°C., medium pitch. The soft pitch is kept in a cooling tank and from there is drawn off into open wooden barrels in which it is usually shipped. Hard pitch is poured into a specially designed pool in the open air. This serves as a storage place. The hard pitch is allowed to solidify, then is crushed into pieces and carried to pulverizers. After being mixed with coke, it is powdered and sold to steel plants for fuel.

Uses of Tar and Tar Products in the United States

Tar.—Tar in undissolved form (straight tar) is utilized in very large quantities as a fuel for open hearth furnaces. A great majority of the

coke oven plants are operated in connection with steel mills, and the tar obtained as a by-product is conveyed without refining to the open hearths and burned as a liquid fuel. In many cases, the tar is almost entirely utilized for this purpose and only a small part of the output is sold to tar distillation plants.

Tar is an excellent material for the construction and repairing of roads. The material which is applied for this purpose is either a straight, undistilled tar (coal tar, water gas tar) or a soft pitch, sometimes a mixture of the two; but whatever the composition, the material is called "road tar." Road tar serves as a binder, and is applied in two ways: It is forced into the interstices of a layer of stone after it is placed on the road (such a pavement is called bituminous macadam), or it is mixed with stone before it is placed on the road (in this case the pavement is called bituminous concrete). Hot tar is applied in both instances, the temperature ranging from 100° to 150°C.

Road tar is also used for preserving roads, and for settling road dust. For these purposes a coat (blanket) of tar is applied to the surface of the road. The tar may be cold or hot for application.

Dehydrated tar is used for making saturated tar felt paper (roofing paper) but asphalt is more or less replacing tar for this purpose at the present time. Dry felt paper is treated with hot tar in saturator baths, and the excess of tar is removed by passing the saturated felt paper between heated rollers. Tar fumes are given off from the baths and strong exhaust ventilation is necessary to remove them.

Dehydrated water gas tar is utilized for shingle stain.

Light Oil Fraction.—This is very seldom used in the crude stage. Some of the larger plants produce benzene, xylene, toluene, etc., the use of which is not considered here.

Naphthalene and Anthracene.—Naphthalene and anthracene are used mainly in the dye industry. The former is a starting point for making azo and phthalein colors. The latter on oxidation gives anthraquinone, a derivative of which is alizarin, an important red dye. Crude naphthalene is sometimes mixed with hard pitch and the mixture is sold as a liquid fuel.

Phenols and Cresols.—Phenols and cresols are used for making disinfectants and germicides; a large quantity is utilized for manufacturing synthetic phenol formaldehyde resins. Cresols (meta, ortho, para) are used for making certain coal tar colors.

Creosote Oil.—By far the greatest demand for creosote oil is in the wood preserving industry, owing to its excellent antiseptic and waterproofing properties. To increase these properties the high boiling tar acids are retained in the creosote oil, for they are very important factors in the protection of wood. As was mentioned above, creosote oils differ very much in their chemical composition: Some contain more naphthalene, others more tar acids; again, some are mixed with straight water gas tar or coal tar. The oil itself is usually a distillate of pure coal tar or of a mixture of coal tar and water gas tar. A very extensively used creosote oil consists of 90 per cent. oil and 10 per cent. straight coal tar. In the wood preserving industry it is chiefly used for treating railroad ties, and

telephone and telegraph poles. The application is very simple. Oil is applied to the wood with a brush, or the timbers are dipped in oil (open tank method) or pressure is employed to drive in the oil (closed tank method).

Pitch.—The chief uses of pitch are the following:

1. Fuel. Soft pitch in place of tar is sold to steel plants (open hearths). Also hard pitch mixed with coke is utilized for fuel (pitch coke).

2. Road construction. This has already been discussed.

3. Roofing. Soft or medium pitch, residue of a mixture of coke oven and gas house tar, is the best material for roofing. Roofing pitch is delivered in barrels and must be remelted. Several layers of tar felt paper are placed on the roof and hot pitch is poured over each layer. The pitch for waterproofing of tunnels, bridges, underground constructions, etc., is applied in a similar way.

4. Protective coatings for pipes; insulation of dry batteries; ingredient in metal paints.

5. For core compounds and in carbon manufacturing, etc., hard pitch is used as a binder. In the United States the use of coal tar pitch binder for making briquettes is very rare at the present time. Asphalt pitch (petroleum asphalt) is used almost entirely.

Occurrence of Skin Cancers among Tar and Pitch Workers

Previous Studies

Statistics from foreign countries show a more or less high incidence of epithelioma among workers handling tar and tar distillation products. Experimental work has proved beyond doubt that tar will cause epithelioma on the skin of certain laboratory animals. It is beyond the purpose of this study to deal with the results of the experimental work which attempts to isolate the active substance in the tar that is responsible for the development of cancer. An excellent review of the literature of this subject by W. H. Woglom appeared in the *Archives of Pathology and Laboratory Medicine* (5).

Kennaway (6) published the statistics of the British Home Office, according to which during the period 1920 to 1923, there were reported among tar workers thirty-four skin cancers distributed about equally between the three areas: scrotum, head and neck, arm and hand.

Tar.—Among the different kinds of tars, blast furnace tar proved to be harmless, for there is neither industrial nor experimental evidence to show that this kind of tar possesses cancer producing power. On the other hand, gas works tar has strong cancer producing properties, especially the high temperature horizontal retort tar, which according to Deelman (7) causes epithelioma on the skin of mice in a much shorter time than the low temperature gas works tars.

As far as coke oven tar is concerned, Leymann, quoted by Kennaway, mentions four cases of cancer among coke oven workers; Bridge and Henry (8) reported eight fatal cases of cancer of the skin among coke oven workers in England and Wales during the period 1912 to 1926, and seven cases (one fatal) among workers in producer gas plants.

There is no information regarding the cancer producing power of water gas tar.

Among the tar distillation products the following proved to be carcinogenic either experimentally or by industrial evidence:

Creosote Oil.—Several cases of cancer (mostly scrotal cancer) occurred among men using creosote oil in different occupations: treating timber, lubricating die molds, etc. (1). Bridge and Henry (8) mentioned six cases among brick, tile, and pipe pressers, and four cases among creosoters of timber.

Green Oil.—Green oil caused a few cases of cancer among grease workers (1).

Forty Per Cent. Anthracene (solid part of the anthracene oil fraction).—O'Donovan (9) described three cases of cancer (hand, cheek, wrist) among workers handling 40 per cent. anthracene in an alizarin factory. Bridge and Henry (8) reported four cases among anthracene workers.

Pitch.—The most harmful substance among tar products is undoubtedly pitch. During the period 1920 to 1923, 100 cases of skin cancer were reported to the British Home Office among workers handling pitch. The lip-cheek and eye-eyelid areas proved to be the parts most liable to cancer.

In the United States, Schamberg (10) described five cases of cancer among tar workers who were engaged in making saturated roofing paper and had been exposed to tar for from thirteen to fifty-five years. One had an epithelioma of the scrotum with preliminary skin irritations. In the other cases, the cancers were located on the hands and wrists of the workers.

Recently Wood (11) conducted an investigation concerning the occurrence of tar cancer in the state of Pennsylvania. He examined eighty-eight tar handlers in six gas works, six coke by-product plants, five plants making briquettes, and in the largest plant handling tars and similar substances. He found a few warty conditions, but no epitheliomatous changes. Among men engaged in creosoting railroad ties and wooden paving blocks, about twenty complained of burns from the splashing of the creosote and from handling it, but they showed no other effects. The Philadelphia Gas Company, employing 750 workers, reported no cases of cancer. Similarly, Wood's investigation among workers handling water gas tar, and those employed in briquette making plants, gave negative results.

Present Investigation

During the course of the present investigation, tar producing and distillation plants and factories where tar products are utilized were visited. Evidence concerning the occurrence of occupational cancer was obtained by examining the records of cancer clinics and hospitals, and by interviewing plant physicians and private physicians treating workers with skin affections.

In the tar distillation operations nearly every man comes in contact with tar or tar products. Unloading tanks means a constant exposure to liquid tar. Stillmen and pumpmen are exposed to vapors, and their hands, arms, and faces may be splashed with liquid tar or pitch. The men engaged in naphthalene plants (centrifuging) handle oil soaked naphthalene crystals; also, tar workers have the habit of removing tar and pitch from their skin by

washing with heavy oils. Where hard pitch is made, the men are exposed to pitch dust. Especially large amounts of dust are given off in the crushing and pulverizing operations. Tar vapors and splashing of tar constitute the hazards in the manufacturing of tar roofing paper, which is usually carried out in connection with distillation operations.

In spite of the distinct exposure to tar, the incidence of cancer is very low in distillation plants. In ten tar distillation plants of the American Tar Products Company, employing about 300 men, no injurious effect due to tar or tar products has been experienced. The Company uses for distillation chiefly coke oven and water gas tars, a much smaller amount of horizontal retort tar, and even less producer gas tar. Other distillation plants in Chicago producing chiefly pitch for paving, roofing, and fuel, and creosote oil for wood preserving, have reported no cases of skin affections apart from occasional burns due to hot tar and pitch. A similar picture was given by Dr. Wood (11) regarding the Barrett distillation plant, the physician of which reported only a few warty growths among 500 handlers of tar and tar products, but no cancers. This Company gets tar from gas refineries and steel plants, and the men are examined annually.

I have discovered only two cases of skin cancer which have occurred among tar distillation workers. Both were treated in the Memorial Hospital, New York (see Table 1).

In coke oven and gas works plants, the workers come in direct contact with tar, the chief hazard being splashing of the tar on their arms, hands, and faces. Gas stokers at the retorts are particularly so exposed. During the operations on the top of the coke ovens, occasionally hot tar splashes up from charging holes, causing burns on the exposed part of the skin of the workers. The same danger is encountered at the hydraulic seals and separator tanks. Particularly great exposure is connected with the cleaning of tank cars, and also with the loading and unloading of cargoes of tar. Negroes are engaged mostly in these latter operations. Besides this direct contact with tar, vapors are given off from the ducts which convey the tar.

Regarding the incidence of cancer in the United States, there is a marked contrast between gas works tar and tars of other origins. The incidence of cancer is very low among coke oven workers, and I have no evidence of any cases of skin cancer among workers engaged in water gas plants. In Chicago the gas company operates eight plants which produce water gas and coke oven gas tar but no gas works tar. The physicians of the company, who make frequent examinations of the employees, and the dermatologists, who treat employees with skin affections, have not seen any cases of skin cancer among tar handlers. Burns very often occur without any serious after effects. Similar reports were obtained from the physicians of the Chicago By-Product Company, which manufactures coke oven, water gas, and producer gas, and by-products; and from many other coke oven and water gas manufacturing plants in New York, Boston, Pittsburgh, Chicago, and Milwaukee.

The situation is not the same with regard to gas works tar. In the

Memorial Hospital, New York,[1] twelve cases of skin cancer, probably caused by tar, were treated during the period from 1920 to 1927, and in the New York Skin and Cancer Hospital seven cases from 1926 to 1928. Table 1 shows the site of the cancer in these cases and the occupations of the men.

Of these nineteen cases of cancer, eleven were due to gas works tar and only one to coke oven tar. It was impossible to trace the source of material with which the roofers had been working, but according to information from different distillation plants, roofing pitch is a residue of distillation of a mixture of coke oven tar and gas works tar.

These results should be compared with those obtained from an industrial plant located in Cleveland, which uses a great deal of pitch. In this plant imported English gas house pitch had been used for making carbon and in dry battery manufacture until 1906, when American coke oven by-product pitch was introduced and has been in use for the same purposes ever since. In the manufacture of carbon, calcined carbon flower (a mixture of lampblack and coke) is softened with light tar oil and then mixed with medium coal tar pitch, which is used as a binder. The mixers are exposed to pitch fumes and pitch dust; the millers engaged in the grinding operations are exposed to

TABLE 1.—ANALYSIS OF NINETEEN CASES OF CANCER CAUSED BY TAR, TREATED IN THE MEMORIAL HOSPITAL, NEW YORK, AND IN THE NEW YORK SKIN AND CANCER HOSPITAL

CASES	SITE OF CANCER	OCCUPATION
3	Nose	Retort man in gas works. Roofer (2).
1	Lip	Stoker in gas works.
5	Face	Stillman (distillation). Stoker in gas works. Retort man in gas works. Roofer. Road worker.
5	Hand	Laborer in distillation plant. Laborer in gas works. Retort man in gas works (2). Coke oven worker.
4	Arm	Stoker in gas works (2). Laborer in gas works. Roofer.
1	Scrotum	Stoker in gas works.

[1] The data from the Memorial Hospital were obtained through the courtesy of Dr. J. Ewing, Professor at Cornell University.

pitch dust. It should be noted that about 1915, exhaust ventilation and a dust collector system were installed, with the resulting reduction of the dust and fume hazard. Another great improvement was made in molding carbon plates; hand molding has been almost entirely abolished and the work is done by hydraulic forcing machines. A few men only engaged in loading and unloading pitch occasionally come in contact with it. In dry battery manufacture a few workers are exposed to pitch fumes and, to a certain extent, to pitch dust, while shoveling the pitch into kettles, in which it is melted to make sealing compound. During the last ten years, twenty-one cases of skin cancer have occurred among workers in this factory; nineteen had handled pitch, while the other two worked in the lampblack department and had had nothing to do with pitch. In their cases the probable cause of the epithelioma was the heavy tar oil, which is used for making the lampblack heavier.

Analysis of these cases, according to the site of the epithelioma, the material used, and the occupation, is given in Table 2. As the figures show, fifteen men were working with gas works pitch and only four with coke oven pitch. The occupational origin of the cancer which occurred among men working with gas house pitch, according to the medical director, is indubitable; it is questionable, however, whether the same can be asserted of three of the four cases which occurred among workers handling coke oven pitch. In the case of the gas house pitch workers, the exposed part of the skin had always shown definite signs of irritation—roughened, reddened, thickened, warty conditions—long before the epithelioma developed. Almost every worker showed the characteristic signs of "pitch irritation" while gas house pitch was in use, but conditions have changed since coke oven pitch has been available. This material is far less irritative; skin irritation does not develop at all, or develops only to a very slight extent. The medical director said that it was easy

TABLE 2.—ANALYSIS OF TWENTY-ONE CASES OF CANCER OCCURRING AMONG WORKERS IN CLEVELAND PLANT USING PITCH

CASES	SITE OF CANCER	MATERIAL	PROCESS	OCCUPATION
7	Hands and arms	Gas house pitch	Carbon mfg.	Molders or mixers.
1	Ear	" " "	" "	Molder.
1	Face	" " "	" "	Molder.
1	Lip	" " "	" "	Molder.
1	Face and hands	" " "	" "	Molder.
1	Wrist	" " "	" "	Mixer.
1	Hand	" " "	" "	Molder.
2	Scrotum	" " "	" "	Molder. Storage man.
3	Lip	Coke oven pitch	" "	Molders or mixers.
1	Scrotum	" " "	Dry battery mfg.	Seal maker.
2	Hand	Tar oil	Lampblack mfg.	Lampblack makers.

to discover from the condition of a man's skin whether he had worked with gas house pitch or with coke oven pitch. In the case of the coke oven pitch workers, the epithelioma developed without any warning signs; the skin did not show any precancerous condition. Also the site of the cancer in three of these cases (lip) is not a characteristic location for pitch cancers. The fourth man, with a scrotal cancer, was exposed to pitch only to a very slight degree and this is the only case which the medical director believes may possibly have been caused by coke oven pitch. The three cases of lip cancer he considers not occupational in character.

It is certainly safe to say, therefore, that the irritating and carcinogenic effect of gas house pitch is much more pronounced than that of coke oven pitch. The records obtained from the New York cancer hospitals show similar pictures. Of the total thirty-seven cases of skin cancer probably caused by tar and tar products, twenty-six occurred among workers handling gas house tar or pitch, while only two occurred among coke oven tar or pitch workers. Legge (12) also pointed out that the pitch and tar from gas works are more toxic than those from coke ovens. Ross and Cropper, quoted by Courmont (13), established the fact that pitch from gas tar is injurious, but not pitch from coke oven tar. Sladden (14) attributes the epitheliomas among patent fuel workers to gas works pitch. It should be noted, however, that there is no experimental evidence as to the absence of cancer producing power in coke oven tar to bear out this industrial evidence.

One would expect that most cases of tar cancer would come from tar distilleries, for the statistics from abroad show the highest incidence of tar cancers among workers engaged in distillation operations. The fact that the occurrence of skin cancers among distillation workers is extremely rare in the United States, may be explained on two grounds. The most important reason is that coke oven tar is used chiefly for distillation purposes and it is less injurious than gas works tar. Water gas tar, the cancer producing power of which is very doubtful, is also used. Even where gas house tar is used, it is generally mixed with either coke oven tar or water gas tar. The same explanation applies to the rarity of skin cancers among workers handling tar products. My investigations in the wood preserving industry, the chief industry in which creosote is used, as well as in tar felt paper making and battery box manufacturing (pitch), gave completely negative results. In roofing and in road making, some positive results were obtained. Altogether, four cases of cancer were found among roofers and one in a road worker. In Chicago several physicians reported to me that they had under their treatment roofers with skin affections, "pitch warts."

The second reason for the rarity of such cancer in the United States may be found in the racial immunity of negroes. In most of the distillation plants negroes are employed about equally with white men. It is a well-known fact that negroes are less susceptible to skin diseases than white men. According to the mortality statistics of the Metropolitan Life Insurance Company (15), the standardized death rate from cancer of the skin

among white males is about three and one-half times that for colored males (white males, 3.4 per 100,000 persons exposed; colored males, 1). Of the twenty-one cases of epithelioma in the Cleveland industrial plant mentioned above, all but one case occurred in white men, although more negroes than whites are employed in the exposed occupations. In the distillation plants and even in the most dangerous operations (tank cleaning, dusty occupations) mostly negroes are employed, and this is another reason why the occurrence of skin cancer is not very frequent in this class of work.

Briquette Manufacturing Industry

According to Ross (16), in England four-fifths of the pitch is consigned to briquette works and the statistics from that country indicate that the principal industry in which pitch cancers occur is the manufacturing of patent fuel.

The frequent occurrence of skin cancers among briquette workers has led to strict regulations in Great Britain governing the manufacture of patent fuel (12). The chief hazard in briquette making is connected with the dusty operations—when the pitch is reduced to small pieces with a pickax, and during the crushing and grinding operations when a large amount of pitch dust is given off. According to Kennaway (1), the irritating character of the pitch leads to rubbing of the face with the hands, whereby particles of pitch are introduced into minute abrasions.

Teutschlaender (17) describes a method known as the Fohr-Kleinschmidt method for elimination of skin cancer among briquette workers. The method consists merely in reducing the dust hazard. Liquid pitch is used, making the work of the pitch breakers unnecessary. The mixing of coal dust with pitch is done in a closed drum, and the workers are thus protected against the detrimental effect of pitch dust.

Wood (11) investigated the briquette making industry in Pennsylvania and in the course of the present investigation briquette manufacturing plants were visited in New England, New Jersey, and Wisconsin. The manufacturing process is very similar in all the plants visited, and according to the information given me, the process described below is, with insignificant differences, applicable to the whole American briquette making industry.

Liquid binder is delivered to the plants in tank cars, which are fitted with steam coils for remelting the binder. When the binder is all melted, it is pumped to the binder tank and then forced by centrifugal pumps to the head of the mixer for mixing it with coal dust. (Anthracite coal is used in the eastern states and bituminous in the middle western states.) A thorough fluxing is done (coating the coal dust with thin layers of binder) by the paddle mixers and malaxeurs. Finally the mixture is molded into briquettes by roll presses.

The binder is almost always petroleum asphalt, for it is cheaper than coal tar pitch. In the American briquette manufacturing industry the use of coal tar pitch is very rare at the present time; it was gradually given up about twenty or twenty-five years ago, and petroleum asphalt was substituted. Even where coal tar pitch is used, it is applied according to the method de-

scribed above: with no crushing or grinding operations, with no pitch dust formation whatever, and without any possibility of the workmen coming into contact with liquid pitch, which runs in a closed pipe system during the whole working process.

These two factors, the use of petroleum asphalt binder and the employment of a purely mechanical process, explain the lack of occupational cancer among American briquette workers. In the course of the present investigation not a single case of skin disease was discovered among briquette makers, and this experience is confirmed by Dr. Wood's investigation in Pennsylvania, which as far as the incidence of skin disease among briquette makers is concerned, gave absolutely negative results.

Summary of Statistical Results and Conclusions

Table 3 gives a review of the total cases of cancer caused by tar and tar products, which were gathered during the present investigation. A summary of the statistical results, together with the conclusions to be drawn from them, follows:

1. The parts most affected are the arms and hands. Fifty-four per cent. of the total cases occurred on the arms and hands; 32.4 per cent. were on the head; while only 10.8 per cent. were on the scrotum.

2. The cancers were caused in 54 per cent. by pitch, in 35.1 per cent. by tar, and in 5.4 per cent. by heavy tar oil.

3. Gas works tar and pitch were responsible for 70.2 per cent. of the cases, while only 5.4 per cent. were due to coke oven tar and pitch. In 10.8 per cent. a mixture of the two, and in 5.4 per cent. heavy tar oil, was the material with which the men had been working. (In 8.1 per cent. it was impossible to trace the source of material.)

The marked contrast in the occurrence of cancers caused by the two kinds of tars indicates that coke oven tar is much less injurious than gas works tar, especially if we take into consideration the fact that coke oven tar is more extensively used than gas works tar, and that more workers are exposed to coke oven tar and its products than to gas works tar.

4. Experimental work undertaken in an attempt to isolate the carcinogenic substance in the tar should be conducted with special reference to the differences in chemical composition between gas works tar and coke oven tar. In this respect the presence of olefins in gas works tar is of particular importance. As will be pointed out later, the probable cause of oil cancer should be looked for in the olefin or unsaturated hydrocarbon constituents of the mineral oil. It is a salient feature that the large majority of these tar cancers were caused by gas works tar, the olefin content of which is one of the chemical characteristics which distinguish it from the less injurious coke oven tar.

5. The occurrence of skin cancers in the United States is very low among distillation operatives, for the most dangerous kind of tar, gas works tar, is not used for distillation to so great an extent as tars of other origin—the most important being coke oven tar, the next, water gas tar, and the least, gas works tar.

6. The occurrence of skin cancers among American tar and pitch workers

TABLE 3.—REVIEW OF THIRTY-SEVEN CASES OF CANCER CAUSED BY TAR AND TAR PRODUCTS, GATHERED IN PRESENT INVESTIGATION

CASES	SITE OF CANCER	MATERIAL	OCCUPATION
6	Face	?	Stillman (distillation).
		Gas works tar	Stoker in gas works.
		Gas works tar	Retort man in gas works.
		Pitch	Roofer.
		Road tar	Road worker.
		Gas works pitch	Molder in carbon mfg.
3	Nose	Gas works tar	Retort man in gas works.
		Pitch	Roofer (2).
1	Ear	Gas works pitch	Molder in carbon mfg.
2	Lip	Gas works tar	Stoker in gas works.
		Gas works pitch	Molder in carbon mfg.
1	Face and hands	Gas works pitch	Molder in carbon mfg.
8	Hand	?	Laborer in distillation plant.
		Gas works tar	Laborer in gas works.
		Gas works tar	Retort man in gas works (2).
		Coke oven tar	Coke oven worker.
		Gas works pitch	Molder in carbon mfg.
		Heavy tar oil	Lampblack maker (2).
1	Wrist	Gas works pitch	Mixer in carbon mfg.
4	Arm	Gas works tar	Stoker in gas works (2).
		Gas works tar	Laborer in gas works.
		Pitch	Roofer.
7	Hands and arms	Gas works pitch	Molders or mixers in carbon mfg.
4	Scrotum	Gas works tar	Stoker in gas works.
		Gas works pitch	Molder in carbon mfg.
		Gas works pitch	Storage man in carbon mfg.
		Coke oven pitch	Seal maker in battery mfg.

is greatly influenced by the slighter susceptibility to skin cancers on the part of negro workers, who are employed about equally with white men in tar handling and distillation operations.

7. Occupational cancer does not occur among briquette workers in the United States because the working conditions obviate dust and contact, and because the use of coal tar pitch is generally eliminated from the briquette manufacturing industry.

Cancer Caused by Mineral Oils

Petroleum consists of various types of hydrocarbons (paraffins, naphthenes), aromatic hydrocarbons, unsaturated hydrocarbons, and many

other non-hydrocarbon constituents (sulphur, resinous compounds, oxygen and nitrogen compounds, etc.).

On the basis of the nature of the residue of their distillation, crude oils can be divided into three groups: (1) paraffin base oils; (2) asphalt base oils; and (3) mixed base oils, which contain both paraffin and asphalt.

W. A. Gruse of the Mellon Institute of Industrial Research (18) gives the classification of the important crude oils according to their sources (oil fields) and their general characteristics, as follows:

1. *Eastern field*, including Pennsylvania, Ohio, and Kentucky. These oils contain largely paraffinic hydrocarbons and are very low in asphalt. The sulphur content is not over 0.1 to 0.2 per cent.

2. *Mid-continent field*, which can be divided into the following subdivisions:

a. Northern and central Texas, Louisiana, and Arkansas yield oils in which the content of paraffin wax is comparatively high, and in which there is more asphalt than in eastern oils; the sulphur content averages 0.2 to 0.4 per cent.

b. Kansas oils are higher in asphaltic content than the other mid-continent oils.

c. Oil from the Oklahoma field resembles the eastern petroleums.

3. *Wyoming field*, extending also into Colorado and Montana. This field produces mixed oils with a comparatively high asphaltic content.

4. *Gulf Coast field* in southern Texas and Louisiana. Oils from this field are predominantly naphthenic in type, but contain upward of 10 per cent. of asphalt. The sulphur content is about 0.75 per cent.

5. *California oils.* The older fields (northern Coast district) yield oils which are naphthenic in type, containing much asphalt but practically no paraffin wax. Recently discovered oils in certain parts of California contain a considerable amount of paraffin wax and are high in asphalt content.

6. *Mexican and South American* (Colombia, Venezuela) *oils.* These contain both asphaltic and paraffinic hydrocarbons, and have a high sulphur content.

Occurrence of Skin Cancers among Oil Workers

The extensive researches of Leitch and Scott proved definitely that certain mineral oils have decided carcinogenic activity. Scott (19) found that there are various skin lesions in Scottish shale oil refineries (folliculitis, papular dermatitis, dermatitis erythematosa, epithelioma). The general cancer incidence in these oil works, however, is not high—0.1 per cent. per annum of the workers employed. Eighty-nine cases of cancer have occurred among paraffin and oil workers from 1900 to 1928. Among thirty paraffin shed men the hands, forearms, and arms were affected in 63 per cent.; among fifty-nine oil workers and laborers the scrotum was concerned in 58 per cent.

Leitch (20) made several experiments on mice with products from a Scottish shale oil company and succeeded in developing tumors. Kennaway and Leitch (6) found that a very active cancer producing material is obtained by passing through a tube at 880°C. a Californian petroleum which in the unheated state has no cancer producing action at all. Also Leitch

(21) describes experiments which were carried out in order to determine whether the noxious property was retained in the more refined oils or whether it was eliminated in the course of preparation of the commercial products. The results of these experiments indicated that the more volatile oils were devoid of tumor producing properties, while the heavier oils (gas oil, cleaning oil, lubricating oil) were carcinogenic.

In the United States, Davis (22) described a case of epithelioma in a man who had been employed for over twenty years in the paraffin department of a large refining company located near Chicago. The epithelioma developed on the forearm after twenty years' work in the paraffin press house and was preceded by warts of the type common among the pressmen.

There is no complaint of skin cancer among workers in oil refineries using crude oils with an asphaltic base. The physician of a large oil refining company in southern Texas wrote me that he had not seen skin diseases caused by petroleum or its products and that the only condition at all common is furunculosis, to which men are subject in proportion to their lack of bodily cleanliness. In the plants in New England and New Jersey using asphaltic oils from southern Texas, Mexico, and Venezuela, the physicians are not aware of any serious skin conditions among workers engaged in distillation processes, in refining crude asphalt or in handling asphalt for making flux (used for the penetration of roofing material), and road and briquette binders. Burns from the hot asphalt and oils are frequent, however. Similar were the statements of the physicians of the oil refineries in Indiana regarding the effect of the purely asphaltic crude oils of Louisiana.

Wood conducted an investigation into the occurrence of skin diseases among oil workers in Pennsylvania (23). His findings are as follows:

According to the mortality records for the eight principal locations where oil is refined, 124 males died from cancer in six years. Only twelve of the 124 men were connected with the oil industry. There were no scrotal cancers in this series and only five skin cancers, none of which occurred in men working in oil occupations.

These results were confirmed by field investigations. The fifteen oil refineries visited used Pennsylvania oils, paraffinic in character, with a negligible amount of asphalt. In these oil companies there were a total of over 1,500 employees, including seventy-six men working in paraffin wax. Local physicians declared that they had never known a wax handler to develop cancer. Some cases of wax boils were reported among workers who remove the paraffin from the canvas bags in paraffin press houses. On the other hand, Dr. Wood examined a considerable number of men who worked over paraffin baths (pure paraffin), but he was unable to discover any damaging effect from this exposure. He stated that pure paraffin is inert and in no way deleterious to the health of persons using it. According to a personal communication, Wood's investigations indicate that cancer is not produced by Pennsylvania oils or paraffins.

The situation does not seem to be quite the same with the mixed base mid-continent oils used in the oil re-

fineries in Indiana and Ohio. These plants refine oils from Texas (northern part), Oklahoma, Kansas, Indiana, Ohio (Lima field). These oils contain both paraffin wax and asphalt; the asphaltic material is such that they may be worked successfully for lubricants. Two of the refineries employ together more than 6,000 workers. The Standard Oil Company of Indiana maintains an excellent medical service with supervision of the employees.

I agree with Dr. Wood's statement that pure paraffin is inert, since these physicians have never observed skin boils or cancers of any kind among workers engaged in the departments where pure paraffin is worked up (candle making, etc.). The boils come chiefly from the paraffin department (paraffin press house) and are very likely caused—as Schamberg stated—by the oily mass from which, during cooling, paraffin separates out. It is certainly true that personal cleanliness plays a great part in the prevention of these wax boils. Elimination is even more assured if the possibility of coming in contact with oils is diminished or excluded. From this point of view, the situation is interesting in the Standard Oil Company of Indiana, where the handwork of filter cleaners has been almost entirely abolished since warm water (heat) has been employed for separating paraffin wax from the oils. About ten years ago 135 to 150 workers were engaged in cleaning canvas filters, and at the present time only eight men are needed to do the same work.

The gradual decrease in the occurrence of wax boils, beginning with the introduction of the new method for cleaning filter presses (1920), is shown in the following figures:[2]

Year	*Cases*
1919	32
1920	14
1921	6
1922	2
1923	1
1924	2
1925	1
1926 on	0

These boils develop largely on the arms and hands, occasionally on the faces of the workers, and they usually cease when the work is discontinued. It is of great importance to eliminate these skin disorders, because they do not always disappear or even maintain their benign character but they may lead, after a shorter or longer period, to epitheliomatous changes of the skin. In one of the big oil refineries in the Middle West there occurred two cases of skin cancer with the following histories:

Case 1.—This man, a paraffin pressman, was treated for "wax boils" for three years, when an epitheliomatous growth developed on his right forearm. This was removed, but eight years after the operation a second growth was removed from the right forearm.

Case 2.—This was a paraffin pressman (cleaner). He had an operation for removal of a squamous-celled carcinoma on the back of his left hand. He had had wax boils several years before the epithelioma developed.

The warty conditions which precede malignancy in these cases are similar to those described by Scott (19) and Leitch (20) who stated that skin cancers among workers in or about the paraffin department are generally pre-

[2] With the permission of Dr. Frank Morton, Medical Director of the Standard Oil Company of Indiana.

ceded or accompanied by warts or other hyperplasias.

The carcinogenic effect of the mid-continent oils is shown by the fact that several cases of skin cancer occurred in another refining company employing 400 workers and using crude oils from Indiana and Illinois, and from the Lima field. The Lima field oils are closely related to the mixed base mid-continent oils. Information about the cases was obtained partly from the Industrial Hygiene Division of the Ohio State Department of Health, to which five cases were reported from 1928 to 1929, and partly from the management and the physician of the plant.

TABLE 4.—ANALYSIS OF EIGHT CASES OF CANCER IN EMPLOYEES OF REFINING COMPANY USING CRUDE OILS FROM INDIANA, ILLINOIS, AND THE LIMA FIELD

YEAR	SITE OF CANCER	OCCUPATION	LENGTH OF EXPOSURE
			years
1926	Arm	Dumper in paraffin pressroom	10
1927	Scrotum	" " " "	5
1927	Scrotum	" " " "	8
1928	Scrotum	" " " "	13
1928	Leg	" " " "	11
1928	Face	Stillman (running still for reduction of crude oil)	4
1929	Scrotum	Superintendent of paraffin dept.	29
1929	Scrotum	Treater in paraffin dept. (engaged in washing tanks)	33

According to the physician, all growths were preceded by warts on the exposed parts of the skin and one case ended fatally. As the data in Table 4 indicate, the length of exposure before the development of the epithelioma varied from four to thirty-three years, the part most often affected was the scrotum, and all the men but one were engaged in the paraffin department. On an average, thirty men are employed in the paraffin department, nine of whom are press dumpers. During the three years 1926 to 1928, five dumpers suffered from epithelioma; this means a very high incidence. In other departments, the occurrence of skin diseases was reported to be very rare, and no trouble was experienced among workers handling refined oils.

The probable reason why the men working in the paraffin press house chiefly are affected is that these men are most exposed to the oil. That epitheliomatous ulceration is not uncommon among stillmen, pumpmen, and other oil distillation workers, however, is shown by the occupation of the patients who were treated for cancer of the skin in the Memorial Hospital, New York, and in the New York Skin and Cancer Hospital, from 1920 to 1927 (Table 5). (It was impossible to obtain information about the kind of oil with which the men had been working.)

In two of the cases the epithelioma

TABLE 5.—ANALYSIS OF ELEVEN CASES OF CANCER CAUSED BY MINERAL OILS, TREATED IN THE MEMORIAL HOSPITAL, NEW YORK, AND IN THE NEW YORK SKIN AND CANCER HOSPITAL

CASES	SITE OF CANCER	OCCUPATION
1	Lip	Oil pumpman.
1	Face	Oil pumpman.
3	Arm	Stillman. Dumper in paraffin pressroom (2).
3	Hand	Worker in oil refinery. Dumper in paraffin pressroom (2).
3	Scrotum	Oil pumpman. Worker in oil distillation plant. Same (cleaner of stills).

TABLE 6.—REVIEW OF TWENTY-ONE CASES OF CANCER CAUSED BY MINERAL OILS, GATHERED IN PRESENT INVESTIGATION

CASES	SITE OF CANCER	OCCUPATION
2	Face	Stillman. Oil pumpman.
1	Lip	Oil pumpman.
5	Arm	Dumper in paraffin pressroom (4). Stillman.
4	Hand	Worker in oil refinery. Dumper in paraffin pressroom (3).
1	Leg	Dumper in paraffin pressroom.
8	Scrotum	Superintendent of paraffin dept. Treater in paraffin dept. Dumper in paraffin pressroom (3). Oil pumpman. Worker in oil refinery (2).

(of the scrotum) developed after ten and twenty years' exposure, respectively. The foregoing data correspond to Scott's findings (24). Scott stated that several cases of cancer of the scrotum had occurred among workmen who were not employed at the paraffin presses, but who dealt with subsequent processes.

Table 6 gives the review of the total cases of cancer caused by mineral oil, which have been gathered during the present investigation. Sixty-two per cent. of the total cases occurred among

workers engaged in paraffin extraction. In 43 per cent. of the total cases the arm and hand were the affected parts; in 38 per cent., the scrotum. The high incidence of scrotal cases is significant —there were approximately four times as many scrotal cancers as in the case of tar workers.

The foregoing data indicate that workers are exposed to the deleterious effect of unrefined oil in almost every kind of operation, and only personal cleanliness, individual susceptibility, and the degree of contact with oils seem to be the factors which influence the frequency of occurrence of cancer. But it is obvious that certain kinds of oils have decided carcinogenic properties in their unrefined stage.

Process of Oil Refining and Cause of Oil Cancer in the United States

Searching for the active substance in the oil which may be responsible for the development of epitheliomatous growths, one may draw certain conclusions:

a. From the reactions taking place during the refining, which seem to destroy the cancer producing activity of the distilled oil. So far, the occurrence of skin cancer from the use of refined lubricating and spindle oils is unknown, or at least insignificant, in the United States.

b. From those substances which are left in the refined lubricating oils and which have proved to be irritative in varying degrees, but not carcinogenic.

The refining of oil is based on the effect of sulphuric acid on the undesirable impurities of the oil. The degree and kind of refining varies with the nature of the crude oil and with the required quality of the refined oil.

For making lubricating oils the distilled oil is treated with sulphuric acid; then the acid is neutralized by bleaching with caustic soda, and the oil goes through intermediate washings. A new method is used extensively at present: The acid treated oil is mixed with clay and the emulsion is broken by alcohol or sulphonated soaps. The strength of the acid is 93 to 98 per cent.; the amount varies according to the degree of refining.

According to Zaloziecki (quoted by Gruse (18)), the characteristics of the sulphuric acid reaction are as follows:

1. Sulphur compounds, resins, and petroleum acids are dissolved or precipitated.
2. Nitrogen bases and some unsaturated hydrocarbons are combined with the acid.
3. Unsaturated hydrocarbons are polymerized.
4. Aromatic hydrocarbons are sulphonated.
5. Some unstable hydrocarbons are oxidized.

The special action of sulphuric acid on olefins has been studied by Brooks and Humphrey (cited in (18)). They describe two characteristic reactions: hydrolysis of the olefins, and polymerization of the olefins; other unsaturated hydrocarbons (diolefins, acetylene) are either removed by the acid or converted into more stable forms.

Investigations were carried out by the Houghton Research Staff (25) on human subjects for the purpose of determining the irritating substance of the cutting mineral oils, and it was concluded that organically combined hydrocarbon sulphonates have an irritating effect and that the chemical irritation of the oil upon the skin of the human subjects is in proportion to the

amount of the sulphonated hydrocarbons contained in the various oils. On the other hand, chemists of the Standard Oil Company definitely stated to me, on the basis of their industrial experiences, that the larger the olefin (unsaturated hydrocarbon) content in the oil, the greater the irritation.

From the fact that occupational skin cancer does not occur in the United States among workers handling refined lubricating oils, but does result from certain kinds of unrefined oils, one can draw the conclusion that the refining process—that is, the effect of sulphuric acid—changes the oil in such a way that the cancer producing activity disappears and what remains is only a skin irritating effect, which varies always in relation to the degree of refining, in other words, with the strength and the amount of sulphuric acid used during the refining process.

That the sulphuric acid has a definite destructive effect on the carcinogenic activity of the oils was proved by the experiments of Twort and Ing (26) who made attempts to free the oils from their carcinogenic substances. In their experiments the oils purified by sulphuric acid produced no tumors.

Since the irritating effect of the refined oils is due to the unsaturated hydrocarbon content, one can conclude that in the unrefined oil, the unsaturated hydrocarbons have strong irritating properties which can lead to the development of epitheliomatous changes in the skin. During the process of refinement, the unsaturated hydrocarbon content is greatly reduced and the irritating effect decreased in proportion, although this apparently does not hold in England where refined spindle oil does produce mule spinners' cancer.

With reference to the type of oil used in the United States, however, it appears to be true that the reaction between sulphuric acid and the unsaturated hydrocarbons causes pronounced changes in the composition of the oil, so that the strongly irritative or carcinogenic activity of the unrefined product is reduced in the refined product to a merely irritative but never carcinogenic activity.

It may be said, therefore, that mineral oils vary in carcinogenic activity according to their olefin or unsaturated hydrocarbon content. There is no method for the determination of the amount of olefins in the various crude oils; if such a method existed, it would be possible to measure the cancer producing power of one or another mineral oil.

Mule Spinners' Cancer

The frequent occurrence of cancerous ulceration on certain parts of the skin among mule spinners was brought to light by Southam and Wilson in 1922. They stated that 141 patients suffering from cancer of the scrotum had attended the Manchester Royal Infirmary from 1902 to 1922 and out of these 141 patients, sixty-nine were mule spinners (27).

Since that date the importance of this question has induced several investigations in Great Britain. In 1925, the Secretary of State for the Home Department appointed a committee to consider evidence as to the occurrence of epitheliomatous ulceration among mule spinners (28). The committee found records of 539 cases of skin cancer among mule spinners from 1876

onward. The liability to scrotal cancer among mule spinners is shown by the fact that the annual death rate from cancer of the scrotum for workers employed in cotton spinning processes is much higher than that for any other group of workers, with the exception of patent fuel workers and chimney sweeps. It is shown also that the incidence of the disease has been rapidly increasing.

The site of the cancer was mainly on the scrotum, especially its anterior aspect on the left side. Other parts of the skin particularly affected were the head (face), neck, and arms.

It is of great importance that investigations be conducted in other countries than England in order to determine the extent of this affection in cotton mule spinners and to reveal certain facts which may bear on the etiology of the disease.

Among the several opinions as to the cause of the disease, that of Southam and Wilson should first be mentioned (27). They believe that the cancer is caused by a combined effect of mechanical irritation and of chemical action of the lubricating oil. Their opinion is based upon the following facts. The piecing work of the spinner necessitates his constant leaning over the faller shaft of the carriage. While he is bending forward the left groin and the left side of the scrotum come in contact with the faller shaft, and this repeated traumatism against the machine causes a chronic irritation of the scrotum. At the same time his clothes become contaminated with oil from the faller shaft, which is moist with lubricating oil thrown off by the revolving spindles. They examined the trousers of the workers and found "a well-marked oil zone . . . . across the body at the level of the upper part of the thighs and lower abdomen. This oil penetrates the trousers and the lower border of the shirt also becomes soaked with it."

The Departmental Committee mentioned above placed the responsibility on the prolonged action of the mineral oil. The Committee considered such additional factors as mechanical irritation, high temperature and moisture in the mills, personal cleanliness, and colored overalls, as of very minor importance, and having no direct influence on the disease. Its investigations were confirmed by experiments of Archibald Leitch (21), who developed cancer on mice by anointing them with certain kinds of mineral oil.

An exactly contrary opinion is held by James Robertson (29), who says that neither the oil, nor the friction due to leaning over the faller shaft, has anything to do with the cause of the cancer. According to him, the spinner does not come into contact with the oil and in the act of leaning, no friction takes place. He attributes the real cause to a pressure which results from the shoulder pull upon an inelastic brace causing the overall fork to operate on the scrotum. This movement takes place while the spinner pieces, stretching out his left arm and raising his left shoulder. Other contributory factors, which add to the effect of the rapid, intermittent friction, are the aniline dye and hard material of the overalls, as well as the dirty scrotum due to the lack of cleanliness of the spinner and to the increased perspiration from the hot and humid air.

Mule Spinning in the United States

Extent of Mule Spinning.—Cotton mule spinning in the United States is almost entirely confined to the New England States. The amount of mule spinning is gradually decreasing owing to the substitution of another method, called "ring spinning," which is a less expensive manufacturing process.

TABLE 7.—APPROXIMATE NUMBER OF MULE SPINNERS EMPLOYED IN THE UNITED STATES IN 1926 AND 1929, AND THEIR GEOGRAPHIC DISTRIBUTION

PLACE OF EMPLOYMENT	NO. OF MULE SPINNERS	
	1926	1929
Adams, Mass.	97	60
Baltic, Conn.	33	..
Fall River, Mass.	120	40
Holyoke, Mass.	29	..
Lawrence, Mass.	126	..
New Bedford, Mass.	400	200
North Pownal, Vt.	10	..
Providence, R. I.	137	..
Pawtucket, R. I.	...	80
Plainfield, Conn.	17	20
Warren, R. I.	64	..
Westerly, R. I.	72	60
Taftville, Conn.	...	60
Moosup, Conn.	...	10
Newark, N. J.	...	20
Total	1,105	550

Table 7 contains data obtained through the Mule Spinners' Association, which show the approximate number of mule spinners employed in the United States in 1926 and 1929, and their geographic distribution. These data indicate that from 1926 to 1929 the number of persons so employed lessened considerably, and that almost half of all the mule spinners are employed in the cotton mills in New Bedford, Mass.

Working Process and Other Working Conditions.—Fourteen cotton mills were visited in New Bedford and Fall River, Mass. The investigation included the observation of conditions under which the work of the mule spinners is carried out.

The spinning mules are very similar in type; most of the mills use machines made in England. The spinning mule consists of two parts: the stationary creel and the moving part, called the carriage. The creel holds the bobbins and a row of rollers (delivery rollers) for forwarding the cotton to the spindles. The carriage runs 64 inches from and to the creel containing the bolster, which in turn carries the spindles on which the cotton threads are to be spun. The spindles pass through the holes in the bolster and their bases rest in cups, commonly called "steps." These cups are subjected to oiling at intervals of about seven to ten days; the other part where oil is applied is the bolster, which is oiled once or twice a day. The spindles are cleaned every two weeks.

In front of the row of spindles at a distance of 5 to 7.5 inches are two metal rods (faller shafts, bars), standing 32 or 33 inches above the floor. Under the faller shafts there are wooden doors (carriage doors) which cover the lower part of the spindles with their steps.

Apparently the machines are the same as those in use in England, and consequently there is no difference in the work of the mule spinner. Many of the foremen and older workers had worked in the Lancashire district be-

fore they came to the United States, and secured their practice in mule spinning in England. They definitely stated that there is no difference whatever between the work of the mule spinner in Great Britain and in the United States.

The work is carried out as follows: The spinner follows the movement of the carriage and when the cotton thread breaks, he pieces the broken end to the delivery roller. In order to reach the broken end of the yarn (cotton thread) he is obliged to bend forward to some extent, depending upon the distance between the carriage and the creel. While he is piecing with his left hand he leans over the faller shaft, stands on his left foot and stretches his right leg back, using it as a counterbalance. The piecing is done approximately 150 to 170 times in an hour. During this work his overalls get into contact with the faller shaft and with the carriage door, but while he is bending over the machine one does not get the impression that this contact exerts any pressure against his body.

It is part of the mule spinner's work to clean the machine, and this requires him to kneel on the oily floor. The oiling of the spindles is also his duty. The floor of the mule room in almost every instance is thickly covered with oil. The temperature varies from 80 to 85°F., with a relative humidity of 60 to 62 per cent.

The spinners work in blue overalls made of a hard material, the color used in the fabric being an aniline dye. The overalls are supported by inelastic braces, no elastic shoulder straps or waist belts being worn; the overalls in some cases are loose, in other cases, tight. Washing and change of the working clothes takes place every week. All the spinners wear an undergarment, which consists in a woolen or a linen shirt, depending upon the temperature of the mule room. Usually they work barefooted; some of them wear shoes, but never socks.

Incidence of Scrotal Cancer among Mule Spinners in the United States

An inquiry as to the extent of scrotal cancer among mule spinners in the United States was made by Frederick Hoffman (30), who stated that in the United States registration area during 1926 a total of thirty-three deaths from cancer of the scrotum were reported, of which six occurred among textile workers, three of whom were mule spinners. Further investigation revealed the fact that of these six textile workers four were born in England and two in Canada; this suggests the possibility that the disease was not contracted in the United States.

This is the only study dealing with the incidence of mule spinners' cancer which has been made up to the present. In the course of the present investigation the data were collected from different sources. In three cities (Lawrence, New Bedford, and Fall River) all death certificates were examined; further information was obtained by looking up the records of cancer clinics and hospitals drawing patients from these regions, and by personal communication with the hospital and plant physicians.

Table 8 shows the number of deaths from cancer among mule spinners, other mill operatives, and persons in other occupations in Fall River and

New Bedford, Mass., during the period 1926 to 1928.

In Lawrence, Mass., sixty-eight mill operatives died from cancer from 1926 to 1928. In two cases the site of the cancer was on the skin (face, neck), but the occupation was not mule spinning in either case.

One may suggest that the foregoing figures do not mean much so far as the primary location of cancer is concerned. The records are really more or less incomplete, but by following up the cases, and checking up the hospital records and histories, I have not been able to trace any other contributory causes than those recorded on the death certificates. This investigation covered, not only the mule spinners, but in many cases, mill workers who had been employed in any kind of mill operation and who had died from any kind of cancer.

Plant physicians of the cotton mills, as well as the superintendents of the fourteen plants visited, definitely stated that they did not know of any case of scrotal cancer among the employees.

Hospital records were examined in Boston and in the cities where most of the cotton mills are located, with the following results:

St. Luke's Hospital and Cancer Clinic, New Bedford, Mass.—There were treated fifteen cases of skin cancer during five years (1925 to 1929). Of the fifteen cases, five occurred among cotton mill workers, with the following anatomic distribution of the cancers: face, two; thigh, two; right side of the scrotum, one. None of these occurred among mule spinners.

TABLE 8.—DEATHS FROM CANCER AMONG MULE SPINNERS, OTHER MILL OPERATIVES, AND PERSONS IN OTHER OCCUPATIONS IN FALL RIVER AND NEW BEDFORD, 1926 TO 1928

SITE OF CANCER	FALL RIVER			NEW BEDFORD		
	Mule Spinners 120[1]	Other Male Mill Operatives	Other Occupations Including Females	Mule Spinners 400[1]	Other Male Mill Operatives	Other Occupations Including Females
Scrotum	..	..	..	..	..	1
Other parts of skin	1	1	15	1	3	7
Cancers other than skin	1	28	391	2	25	301
Total	2	29	406	3	28	309

[1] This figure shows the average number of cotton mule spinners employed in that city in 1926.

General Hospital, Lawrence, Mass.—During six years, three mill operatives (no mule spinners) were treated for skin cancer.

Union Hospital, Fall River, Mass.—All records were examined from 1923 up to the present. Only two mill operatives were treated for skin cancer (cancer of the face).

Cancer Clinic, Fall River, Mass.—There were treated altogether twelve

cases of skin cancer among males in 1928 and 1929. Of these, four were mill operatives (one suffered from scrotal cancer), but none of them were mule spinners.

Massachusetts General Hospital, Huntington Memorial (Cancer) Hospital, and City Hospital, Boston, Mass.—In these three hospitals twenty-five cases of cancer of the scrotum were treated during the period from 1887 to 1928. The cases according to occupations are as follows:

Occupation	*Year*
Laborer	1887
Laborer	1893
Farmer	1896
Ironworker	1898
Mule spinner	1901
Mule spinner	1903
Farmer	1908
Mule spinner	1912
Florist	1914
Mule spinner	1914
Comb factory worker	1915
Servant	1915
Laborer	1915
Farmer	1917
Leather worker	1918
Mule spinner	1919
Painter	1921
Foundry worker	1921
Engineer	1921
Painter	1925
Clerk	1925
Teamster	1927
Mule spinner	1927
Merchant	1927
Servant	1928

As these data indicate, of the twenty-five cases of scrotal cancer, six occurred among mule spinners, from 1901 onward. It was impossible to trace back the case which occurred in 1901; the occupational histories of the other five cases are as follows:

Case 1.—J. O. (1903) came from England, where he had been a mule spinner for a long time. He had worked in New Bedford and Lawrence as a mule spinner for two or three years before the epithelioma developed.

Case 2.—C. B. (1912) had been a mule spinner in Massachusetts for twenty-two years.

Case 3.—D. J. (1914) had been a mule spinner in New Bedford for ten years.

Case 4.—R. J. (1919) had been a mule spinner for about twenty years in the Lancashire district and Scotland. He worked for only one year in the United States before the epithelioma developed.

Case 5.—R. J. (1927) was a mule spinner in England prior to his coming to this country. He worked in different cotton mills in the United States for only a short time.

Thus, of the six cases, only two were positively contracted in the United States; the others were possibly due to the mule spinning occupation in which the men were engaged for a long time in England.

These evidences demonstrate that the occurrence of scrotal epithelioma among mule spinners is insignificant in the United States and that during the last fifteen years not a single case has occurred which can be attributed to the American mule spinning occupation.

Cause of Mule Spinners' Cancer

Whether the mule spinner is exposed to a mechanical irritation due to the repeated act of leaning against the faller shaft or to the pulling of the overalls as Robertson believes, I was unable to discover. But whatever irritation takes place, it cannot have any influence on the causation of this form of cancer. As described above, the working process in every possible detail is the same in the United States as in England, the spinners wear the same kind of overalls as they do in England, and the atmospheric conditions in the

mill room and other working conditions are very similar, too. Consequently, the worker in the United States is exposed to the same kind of mechanical irritation and exactly to the same degree as is the spinner in the Lancashire district; yet the occurrence of scrotal cancer among mule spinners is insignificant in the United States. This fact excludes mechanical irritation as having anything to do with the cause of the cancer.

The chemical action of the lubricating oil remains as a sole cause of the cancer, as is claimed by Archibald Leitch and others. As no case of mule spinners' cancer has been found in the United States during the last fifteen years, the absence must be attributed to one of two possibilities: Either the worker does not come in contact with the oil, or the spinning oil used in the United States has no carcinogenic activity.

The oiling of the bolster is done once or twice a day. Immediately after the oiling, oil is thrown off by the revolving spindles in the form of a spray which disappears within a few minutes. Most of the oil spreads on the carriage door, which is always thickly covered with oil; the spray does not reach the faller shaft. The amount of oil sprayed depends on the cleanness of the spindles. The faller shaft in most cases is free from oil; there were only three mills in which the faller shafts were covered with a thin oil layer. In some cases, however, the faller shaft, as well as other parts of the machine, becomes contaminated with oil as a result of careless oiling.

It is very easy to discover some oily areas on almost every man's overalls. The vicinity of the knee is covered with oil, probably from contact with the carriage door and from kneeling on the oily floor during repairing and cleaning. There is an oil zone on the upper thighs under the groin or in the gluteal region, from 2 to 5 inches in width. This contamination is caused by the rubbing of oily hands on the overalls. In many cases other parts of the overalls as well as the shirts (sleeves and lower border) of the men were found soaked with oil.

Since, therefore, contact with oil is obvious, and since the men are exposed to the oil with no cancer resulting, we can safely state that the spindle oil in the United States must be quite innocuous.

The crude oils which are used for making spindle oils are from different sources, but chiefly Pennsylvania and mid-continent crude oils are chosen—they have a lower vapor pressure, and the lubricating oils obtained from them are best suited for lubricating high speed machines.

The reason that lubricating oils and other refined oils have no carcinogenic properties has been explained in the preceding section, on the ground of the effect of sulphuric acid on the cancer producing substances of the oil. The same explanation holds good to an even greater degree with regard to the harmless character of the spindle oils, for the refining of spindle oils is carried out more drastically—that is, larger quantities and stronger solutions of sulphuric acid are used. This drastic acid treatment insures the removal of impurities, and produces a type of lubricating oil which is best suited for the purpose of lubricating high speed machinery and which will not oxidize in the high humidity of the spinning

room. Owing to strong acid treatment, the removal of olefins and other unsaturated hydrocarbons is carried out very effectively. As has already been stated, olefins are the probable factors which cause epitheliomas among oil refinery workers; their removal from spindle oil insures the harmless character of the oil, which in turn explains the absence of occupational cancer among mule spinners in the United States.

BIBLIOGRAPHY

1. Kennaway, E. L.: On Cancer-Producing Tars and Tar-Fractions. This Jour., 1923–1924, *5*, 462.
2. Odell, W. W.: Preparation and Uses of Tar and its Simple Crude Derivatives. U. S. Bur. Mines, Tech. Paper 268, 1922.
3. Rogers, A.: Industrial Chemistry. A Manual for the Student and Manufacturer. Second edition. New York, D. Van Nostrand Co., 1915, p. 466.
4. Huff, W. J.: The Distillation of Coke-Oven Tar and the Recovery of Some of its Products. Chem. and Metall. Engin., 1922, *26*, 113.
5. Woglom, W. H.: Experimental Tar Cancer. Arch. Path. and Lab. Med., 1926, *2*, 533, 709.
6. Kennaway, E. L.: The Anatomical Distribution of the Occupational Cancers. This Jour., 1925, *7*, 69.
7. Deelman, H. T.: Über experimentelle maligne Geschwülste durch Teereinwirkung bei Mäusen. Ztschr. f. Krebsforsch., 1922, *18*, 261.
8. Bridge, J. C., and Henry, S. A.: Industrial Cancers. Report of the International Conference on Cancer, London, July, 1928, held under the auspices of the British Empire Cancer Campaign. Bristol, John Wright & Sons, p. 258.
9. O'Donovan, W. J.: Carcinoma Cutis in an Anthracene Factory. Brit. Jour. Dermat., 1921, *33*, 291.
10. Schamberg, J. F.: Cancer in Tar Workers. Jour. Cutan. Dis., 1910, *28*, 644.
11. Wood, H. B.: Skin Lesions among Tar Workers. Jour. Cancer Res., 1929, *13*, 54.
12. Legge, T. M.: Epitheliomatous Ulceration in Industry. Brit. Med. Jour., 1922, *2*, 1110.
13. Courmont, P.: Tar Cancer in France. Jour. State Med., 1924, *32*, 539.
14. Sladden, A. F.: Pitch Cancer. Report of the International Conference on Cancer, London, July, 1928, held under the auspices of the British Empire Cancer Campaign. Bristol, John Wright & Sons, 1928, p. 284.
15. Dublin, L. I., Kopf, E. W., and Van Buren, G. H.: Cancer Mortality among Insured Wage Earners and their Families. The Experience of the Metropolitan Life Insurance Company, Industrial Department, 1911 to 1922. New York, Metropolitan Life Insurance Co., 1925.
16. Ross, H. C.: Occupational Cancer. Jour. Cancer Res., 1918, *3*, 321.
17. Teutschlaender: Das Fohr-Kleinschmidtsche Pechzerstäubungsverfahren als Verfahren zur Verhütung des Pechkrebses in Brikettfabriken. (Ergebnisse eines Besuches auf Zeche Engelsburg bei Bochum.) Ztschr. f. Krebsforsch., 1929, *30*, 231.
18. Gruse, W. A.: Petroleum and its Products. A Chemical Discussion of the Properties, Refining and Utilization of Petroleum. First edition. Mellon Institute Technochemical Series. New York, McGraw-Hill Book Co., Inc., 1928.
19. Scott, A.: Cancer in Mineral Oil Refineries. Report of the International Conference on Cancer, London, July, 1928, held under the auspices of the British Empire Cancer Campaign. Bristol, John Wright & Sons, 1928, p. 275.
20. Leitch, A.: Paraffin Cancer and its Experimental Production. Brit. Med. Jour., 1922, *2*, 1104.
21. Leitch, A.: Mule-Spinners' Cancer and Mineral Oils. *Ibid.*, 1924, *2*, 941.

J. I. H.
May, 1930

22. Davis, B. F.: Paraffin Cancer. Coal and Petroleum Products as Causes of Chronic Irritation and Cancer. Jour. Am. Med. Assn., 1914, *62*, 1716.
23. Wood, H. B.: Paraffin Not Productive of Cancer. Jour. Cancer Res., 1929, *13*, 97.
24. Scott, A.: The Occupation Dermatoses of the Paraffin Workers of the Scottish Shale Oil Industry. Eighth Scientific Report of the Imperial Cancer Research Fund. London, 1923, p. 85.
25. Causes of Skin Sores and Boils among Metal Workers. An Investigation by the Houghton Research Staff. Philadelphia, E. F. Houghton & Co., 1920.
26. Twort, C. C., and Ing, H. R.: Mule-Spinners' Cancer and Mineral Oils. Lancet, 1928, *1*, 752.
27. Southam, A. H., and Wilson, S. R.: Cancer of the Scrotum: The Etiology, Clinical Features, and Treatment of the Disease. Brit. Med. Jour., 1922, *2*, 971.
28. Report of the Departmental Committee Appointed to Consider Evidence as to the Occurrence of Epitheliomatous Ulceration among Mule Spinners. London, H. M. Stationery Office, 1926.
29. Robertson, J.: An Inquiry in Regard to the Cause of Spinners' Scrotal Cancer. This Jour., 1927, *9*, 217.
30. Hoffman, F. L.: Mule-Spinners' Cancer. U. S. Month. Labor Rev., 1928, *27*, 457.

THE OCCURRENCE OF PULMONARY FIBROSIS AND OTHER PULMONARY AFFECTIONS IN ASBESTOS WORKERS*

E. R. A. Merewether, M.D.

H. M. Medical Inspector of Factories

Introduction

PRIOR to the commencement of this inquiry, in February, 1928, definite knowledge existed of only two deaths of asbestos workers about whom there was expert opinion that the inhalation of asbestos dust had at least contributed to, if not caused, the fatal outcome.

The first of these, in retrospect the most suggestive, only came to light some years after the occurrence, when full information was unobtainable. All that is known of this case, now referred to as "the Montague Murray Case," is contained in the evidence given by Dr. Montague Murray before the Departmental Committee on Compensation for Industrial Diseases in 1906 (1). From this source, we learn that:

> The patient, a male aged 33, came under the care of Dr. Montague Murray at the Charing Cross Hospital in the beginning of 1899. He had worked with asbestos for "some 14 years," 10 years as a cardroom hand, and the remainder in some other room of the factory, "where there was much less dust." He volunteered that, of the 10 people working in the cardroom when he went into it, he was the only survivor, and that all the others had died somewhere about 30 years of age. There is no note as to the nature of his work, previous to that in the asbestos factory.
>
> He was treated in the Charing Cross Hospital for two months, and then returned to work. After a few months, however, he became ill again, and was re-admitted to the Hospital in April, 1900, where he died. The post-mortem examination confirmed the clinical diagnosis of extensive pulmonary fibrosis. There was no evidence of pulmonary tuberculosis, and examination of the sputum for B. tuberculosis was negative.

The second case was reported by Dr. W. E. Cooke in 1924, eighteen years later (2):

> The deceased, a woman, aged 33, who died in 1924, had worked in asbestos for 18 years, but intermittently for the last 5 years, owing to periods of ill-health. The post-mortem examination revealed, not only extensive fibrosis of the lungs, but also much change due to pulmonary tuberculosis.

Although Cooke (3) and Stuart McDonald (4) were conclusively of the opinion that in this case the lungs showed a progressive dust fibrosis, together with a chronic tuberculous infection, the etiologic relationship between the inhalation of asbestos dust and fibrosis of the lungs would have been strengthened by the absence of a tuberculous infection.

Cooke's case is, however, of outstanding importance, not only because of the discovery of "curious bodies" in the lungs—discussed later—but also, and of more importance generally, be-

* Received for publication Feb. 17, 1930.

cause its publication again directed attention to the possibility that inorganic dusts containing little or no free silica may be productive of extensive pulmonary fibrosis. Of these dusts, the silicates form a very large class, of which asbestos is but one example. Many other members of the class, such as the feldspars, kaolin, French chalk, and pumice, are extensively used in industry. The importance, therefore, of delimiting the potentialities of the class as producers of pulmonary fibrosis is clear.

Cooke's case was the first to be generally reported in the medical press; the facts of the Montague Murray case, although contained in the evidence presented before the Departmental Committee in 1906, and published in 1907, were liable to be overlooked in the mass of important material on industrial diseases elicited by that Committee.

Since Cooke's case, Dr. I. M. D. Grieve has made a careful study of a group of asbestos workers in his practice, and has courteously allowed access to his records.

In February, 1928, Dr. MacGregor, Medical Officer of Health for Glasgow, drew my attention to an asbestos worker who was receiving treatment in one of the hospitals in that city. This case, the details of which have been reported by H. E. Seiler (5), presented, both clinically and radiologically, signs of a diffuse pulmonary fibrosis, with no evidence of a tuberculous infection. On further investigation into the patient's industrial and medical history, no presumptive cause, other than the inhalation of asbestos dust, was found to account for the existence of the fibrosis.

This case, at that time the third of which the Factory Department had knowledge, was, however, the first in which the four essential conditions, necessary to establish a relationship between the inhalation of asbestos dust and the development of fibrosis, could be demonstrated. These conditions are:

1. Work involving exposure to asbestos dust.
2. The existence, demonstrable clinically and radiologically, of a definite pulmonary fibrosis.
3. The absence of previous or present infections known to cause pulmonary fibrosis —*e.g.*, tuberculosis, influenza, or pneumonia.
4. The absence of previous or present work involving exposure to other dusts, which might cause pulmonary fibrosis.

These conditions being fulfilled, a relationship between the inhalation of asbestos dust and the development of the pulmonary fibrosis may be presumed.

The importance of establishing whether the supervention of this disease in an asbestos worker was an exceptional occurrence, or evidence of a grave health risk in the industry, was now apparent, and steps were taken, forthwith, to obtain *prima facie* evidence in proof, or disproof, of the existence of such a risk.

A number of workers in asbestos were selected and examined clinically and radiographically. The findings invited further investigation throughout the industry, with the result that a comprehensive inquiry involving the investigation of the different processes in relation to the evolution of dust, and the examination, both clinical and radiologic, of workers, was undertaken during the year 1928, commencing

with the carding, spinning, and weaving processes of the industry.

In the meantime, in March, 1928, the death of an asbestos worker (one of Dr. Grieve's cases) occurred in another part of the country, and, on post-mortem examination, a condition of widespread fibrosis of the lungs, without tuberculosis, was revealed. The microscopic examination also disclosed the presence of the curious bodies.

In 1928, also, Dr. F. W. Simson (6) reported a fatal case of fibrosis of the lungs occurring in a native working in an asbestos mill in southern Rhodesia.

In order that this brief survey of the events leading up to the present inquiry may be complete, it is necessary to review the investigation made in 1910 to 1911 by Dr. Collis and Miss Whitlock—the only previous inquiry into the subject.

In May, 1910, the Registrar-General drew attention to a death which had been certified as "acute pulmonary phthisis in an asbestos worker," and to a statement (for which he was unable to vouch) that seven other deaths from phthisis had occurred in the same factory.

Following this, extensive inquiries were made, a medical report on all the employees in the factory concerned was obtained, and Dr. Collis and Miss Whitlock investigated generally the various processes in the industry with respect to the evolution of dust, methods of ventilation, lost time due to sickness, etc. Also inquiries were made of the Canadian government as to the conditions in the asbestos quarries and mills in that Dominion, evidence of increased sickness and mortality rates among the workers, and any methods of ventilation which had been found of especial value.

The result of this investigation did not conclusively prove that asbestos possessed injurious properties, but it pointed to the probability that such was the case. It is interesting to consider why it was that no conclusive proof one way or the other could be obtained, then, as to the injuriousness of asbestos dust. Some, if not all, of the factors which affected the position then are, in varying degree, continuing factors, and have an important bearing on the present inquiry. Their operation, while providing a solution to this query, also affords an explanation to another pertinent question: Why is it that this industry, founded in antiquity, has only recently excited attention, by reason of its raw material becoming suspected as a cause of industrial disease?

The answer appears to be that in the past it was not practicably possible to obtain proof of the injuriousness of asbestos dust, considering the limitations imposed by the state of the industry, and the point reached by research work into the relationship between dust inhalation and diseases of the lungs.

The industry itself, not a large one today, was then (1910) considerably smaller. Certainly it had begun to grow rapidly, but the number of workers who could have been employed for a period of time long enough to allow of the development of definite physical signs of pneumonokoniosis must have been quite small, and dispersed over the country.

Precise knowledge of the morbid affections of the lungs produced by the inhalation of dusts was more fragmen-

tary than it is today. The position was clearly stated two years later in evidence placed before the Royal Commission on Metalliferous Mines and Quarries. This Commission, when reporting in 1914 (7), stated "we do not know whether other dusts besides those containing free crystalline silica induce a pathological condition in the lungs, though the experiments of Professor Beattie in animals suggest that this may occur." It is only in the last year or two that research has produced some definite evidence as to the precise effects of some of these dusts on the lungs (8) (9) (10) (11) (12).

In 1910, radiography of the lungs, in both its technical and its interpretative aspects, was still in its infancy and, so far from having attained its present status of being an indispensable aid to the diagnosis of the dust diseases of the lungs, was an unused ally.

In addition, the existence of a measure of exhaust ventilation in the most dusty processes of the industry, incomplete as it was, had important results in modifying the onset, course, and duration of any pathologic lung conditions resulting from the inhalation of the dust. This influence has been much more pronounced in the period intervening between 1912 and the present inquiry, and will be referred to again.

Another factor which has tended and still tends to obscure the possible deleterious effects of the non-silica dusts, is the general use of the phthisis mortality rate as a comparative index of the degree of injuriousness of the dust encountered in the various dusty occupations. This rate, while of great value in separating dusty industries into two great groups—those which show an excess mortality from phthisis, and those which do not—as well as being a comparative index of the industries belonging to the former group, not only is of little value as a means of classification in the latter group, but also tends to distract attention from it, and to result in the associated dusts being dismissed as more or less innocuous.

Evolution of dust is only one factor, though an important one, which may cause variations in the phthisis mortality rate in different industries. Wages, hours of work, aggregation of workers, amount of food, housing, and other social and environmental conditions are, however, powerful influences in the same direction, and are not necessarily comparable as between the workers in any two industries.

In thus reviewing some of the influences which have retarded recognition of the baneful effects of some dusts upon the lungs, the singular attributes of pulmonary fibrosis, the most important of the diseases caused by the inhalation of dust, must not be overlooked.

This disease, insidious in its onset, stealthily advances with but faint warnings of its progress; inexorably it cripples the essential tissues of the lungs, yet for a considerable period causes almost no inconvenience to the worker. As time goes on, however, the lungs find more and more difficulty in re-aerating the blood; and breathing is quickened on slight exertion. Still the worker is able to remain at work, but is aware of his undue shortness of breath on extra effort. Usually, however, he ascribes it to causes other than the dust he is inhaling.

As the disease progresses, if no acute illness has caused a fatal termination,

a stage is reached when the lungs can do little more than maintain life; and the shortness of breath is extreme. Even in its terminal stages, the disease, deceitful to the last, may masquerade as chronic bronchitis, pulmonary tuberculosis, bronchopneumonia, or the like.

While more or less acute cases of fibrosis closely simulating miliary tuberculosis have occurred, even in this country (13), they have all been associated with the inhalation of dense concentrations of free silica dust, and are, fortunately, the exception rather than the rule.

The difficulty of diagnosing pulmonary fibrosis, especially in its early stages, or if complicated by tuberculosis, has been stressed by a number of authorities, and has, undoubtedly, contributed to impede the attainment of precise knowledge of the extent to which the various industrial dusts affect the lungs.

Difficulties and obscurities still impede, though to a less degree than in the past, any investigation into the effects of an industrial dust upon the lungs of those exposed to it; but prior to the War, although there were certain slight indications that asbestos, in common with some other dusts, might produce permanent pathologic changes in the lungs, it was not possible to obtain evidence sufficient to prove or disprove this hypothesis.

At the outset of the present inquiry into what, if any, pulmonary diseases workers exposed to the inhalation of asbestos dust are more prone to contract than the general population, it was considered essential to view the problem afresh, and with complete detachment, because of the fact that asbestos dust has a totally different physicochemical constitution from that of dusts containing much free silica and causing silicosis. It was felt that although much valuable guidance could be obtained from the methods of investigation of silicious dusts, care had to be taken to keep an open mind, so as not to be unconsciously biased in the direction of assuming that the effects of the dust, if any, must be comparable in some degree to those of crystalline silica.

Asbestos and the Asbestos Industry

Asbestos

The term asbestos is a collective name, of no definite mineralogic significance, which has been applied to a variety of silicate minerals, which differ from one another in chemical composition and physical properties, but which resemble one another in their finely fibrous feature and flexibility (14). Their value depends on the facility with which they are capable of being split up into long and flexible fibers, which can be spun like cotton and woven into cloth; on their resistance to heat and acids; and on their insulating properties with respect to heat and electricity.

Varieties of asbestos possess these qualities in differing degree. Commercially, therefore, selection is made by the manufacturer of that variety and grade which is most suitable for the purpose in view, regard being paid to ordinary economic factors, such as the cost of the raw material, and the price which the finished article may be expected to command.

Consignments of asbestos of the same general variety, but with differ-

ent countries of origin, are frequently mixed in the preliminary processes of manufacture. Thus Canadian chrysotile may be mixed with Russian, or Rhodesian chrysotile, and so on. Less frequently, totally different varieties, such as amosite and chrysotile, may be mixed.

Practically speaking, all that goes under the name of asbestos, in commerce, is either fibrous serpentine or a fibrous mineral of the amphibole, or hornblende, group. The former is the most important commercially; but strictly, the mineralogists confine the term asbestos to fibrous forms of hornblende. These two types are sharply distinguishable, chemically and mineralogically.

Serpentine asbestos, or chrysotile, is a hydrated magnesium silicate, containing practically no calcium, a high percentage of combined water, and a low percentage of iron. This variety is very suitable for spinning, but is attacked by acids. Nearly 80 per cent. of the world's production of asbestos is derived from Canada, and is of this variety; the remainder comes mainly from South Africa and Russia.

The amphibole, or hornblende, varieties contain less magnesium and combined water, and usually more calcium, aluminium, and iron. Members of this group are resistant to acids, but are more difficult to spin, some being quite unsuitable for this purpose. The most important members of this group are crocidolite, amosite, and tremolite.

Crocidolite and amosite are mainly silicates of iron, the former having a beautiful lavender-blue color, the latter being brownish-gray. Both are spun and the yarn is woven into cloth for various purposes, such as acid filtering, and for making into insulating mattresses, as well as for other purposes. Both are produced extensively in South Africa, from which quarter all required commercially is obtained. Amosite, a comparatively recent discovery, is found there in very large deposits; its use is steadily increasing, the initial difficulties associated with the manufacture of textiles from this variety having been overcome.

Tremolite, found in various quarters of the world, has been mined in northern Italy since the time of the Romans. Its chief use is in the manufacture of asbestos millboard and for filtering purposes.

Table 1, compiled from various

TABLE 1.—COMPOSITION OF SERPENTINE AND AMPHIBOLE VARIETIES OF ASBESTOS

MINERAL GROUP	VARIETY	PERCENTAGE OF							
		SiO_2	Al_2O_3	FeO Fe_2O_3	MgO	CaO	Na_2O	K_2O	Combined Water
Serpentine	Chrysotile	39–42.5	0–3.7	0.7–4.4	39–43	0–0.35	...	...	13.3–16.5
Amphibole (hornblende)	Crocidolite	50.5–52.1	0–1	35.5–37.4	0–3	0.75	6.2–9	...	1.6–4.5
	Amosite	48–53	1.2–9.4	34–44	0.7–6.4	....	0–2.5	...	2–3.8
	Tremolite	57.2	0.9	3.2	22.8	13.4	0.6	0.3	2.4

sources, shows the main differences in the composition of these four varieties.

Only a very small proportion of the world's production of asbestos, which is between 300,000 and 400,000 short tons per annum, is suitable for spinning, and the most desirable grades of spinning fiber, consequently, command a high price—now over £100 a ton. The shortage of this grade has led to improvements in manufacturing processes which have enabled less expensive grades of fiber to be utilized for spinning, some of which give rise to an increased amount of dust.

About four-fifths of the world's production of asbestos is fiber unsuitable for spinning, and this is used in the manufacture of asbestos millboard, tiles, sheeting, paper, and many other articles. It is the discovery of industrial uses for these very short fibers, and the dust-like waste, which has been responsible for the phenomenal expansion of the industry as a whole. The spinning and textile section has also shared, because of the extensive use of the yarn and cloth in the manufacture of steam packings, insulating mattresses, brake linings for motor cars, fireproof curtains, and the like.

In 1880, three years after the discovery of the large Canadian deposits, the world production of asbestos was little over 500 short tons; by 1900 it had risen to about 35,000 short tons, by 1920 to over 230,000 short tons, and by 1925 to over 330,000 short tons (15).

The imports of asbestos (all grades) into the United Kingdom rose from 18,591 tons in 1922 to 33,520 tons in 1927 (16). The figures for 1927 refer to Great Britain and northern Ireland only. Of these quantities 8,844 tons and 3,794 tons, respectively, were reexported. Thus the consumption of asbestos in this country trebled within five years.

The Industry

On considering the uses of asbestos one is astonished, not only at the wide range of articles manufactured from this mineral, in greater or less proportion, but also at the diversity of industries which nowadays find its use necessary, either in the form of the raw material, or as manufactured articles.

Evidently, therefore, with the multiplicity of processes and dusts encountered in the ramifications of the industry, discrimination would have to be exercised, and some limit set to the processes included in the inquiry.

The processes selected may be divided, roughly, into

1. Processes involving the manipulation of asbestos, either pure, or admixed with a small proportion of cotton, or other vegetable fiber.
2. Processes involving the manipulation of asbestos together with other dusty materials.
3. Processes involving the making up of asbestos cloth into other articles.

Group 1 entails exposure to asbestos dust mainly, and to cotton, or other vegetable dust, very slightly; group 2 entails exposure to asbestos dust in very varying amounts, and also exposure to divers other dusts, such as brick dust, magnesia, kieselguhr, fossil meal, and cement; in group 3 the exposure to asbestos dust—provided no other asbestos processes are being carried on in the vicinity—is, in the majority of cases, negligible. Processes belonging to all three groups may be carried on in the same factory, and workers may transfer from one department to another (30).

J. I. H.
May, 1930

Investigation into the intricate question of the effects of mixed dusts, while possibly productive of some general corollary, would lose much of its value in the absence of knowledge of the effects of the several component dusts, and moreover would introduce an incalculable variable into the final results. For these reasons, and also because the Montague Murray case, Cooke's, Grieve's, and Seiler's cases all occurred in processes included in group 1, it was considered advisable to exclude, as far as possible, from the inquiry all workers exposed to the influence of mixed dusts, and all those not employed in processes included in groups 1 and 3.

The processes included, therefore, are the crushing, preparing, sieving, opening, mixing, carding, spinning, doubling, plaiting, braiding, and weaving of asbestos, together with the operations incidental thereto. Also included is mattress making, where the filling is asbestos, and the manufacture of some insulating materials, where the dust produced is asbestos.

The carding and spinning processes have many points of resemblance to the corresponding processes in the cotton industry, but with essential modifications and restrictions caused by the different physical characters of the asbestos fiber. These processes are aided by an admixture of cotton, or other vegetable fiber, and usually from 2 to 10 per cent. by weight of cotton is added. More rarely, and for special purposes, long-fibered asbestos is carded and spun with no admixture of vegetable fiber, but usually asbestos yarns contain a core of either cotton or metal wire.

Asbestos yarns are not only used for the weaving of fabrics, which themselves are used for a multitude of purposes, but, braided together, are made into ropes for use as steam packings and other purposes. The interstices and center of the rope may be filled with other materials such as talc, oil, or graphite, depending on the precise use to which the rope is to be put.

Asbestos mattresses, used for blanketing steam engines, and for other insulating purposes, are made of asbestos cloth stuffed with asbestos fiber. The stuffing material may be, however, slag wool, magnesia (containing approximately 15 per cent. of asbestos fiber), or kieselguhr with a small percentage of asbestos fiber. The manufacture of mattresses filled with mixtures of asbestos fiber and other materials has not been included in this portion of the inquiry.

The shortness, slipperiness, and lack of strength of the individual asbestos fiber, as compared with cotton, flax, wool, silk, and other textile fibers, have been the cause of much technical difficulty in manufacture. The efforts of manufacturers to cope with these difficulties, together with those due to wide variations in the physical properties of the raw material, are reflected in the methods employed by each. For these reasons, and because of the great number of patented and special products manufactured, one finds considerable differences in detail in the processes in use.

The majority of the processes mentioned result in the evolution of dust, although by no means to the same extent. Differences in plant, quality of asbestos used, methods of manufacture, type of finished article, and extent of application of exhaust ventilation,

all result in variations in the evolution of dust in similar processes in different factories.

Variations in the evolution of dust in different processes being of outstanding importance, a series of samples of dust from the air of workrooms was collected, by means of the Owens jet apparatus.

Population at Risk.—A calculation of the total number of workers employed in the processes already enumerated as included in this inquiry, but excluding those engaged in processes included in group 3 in which the exposure to asbestos dust is negligible, gives a figure of approximately 1,600; if we could add to this the number of workers engaged in handling pure asbestos fiber only, in the preliminary stages of the processes included in group 2, we should obtain the total population at risk from the effects of asbestos dust itself. Unfortunately, this latter figure is unobtainable; but a rough estimate, and most probably an overestimate, is 600. Thus, about 2,200 appears to be the total population at risk in this country, for the purposes of this inquiry. This figure, however, does not include the large number of workers engaged in the processes in group 2 which involved exposure to the influence of mixed dusts, of which asbestos is but one, and commonly not more than 20 per cent. of the mixture.

This estimate of the population at risk, although it may be excessive, is useful, since it enables us to judge of the adequacy of the sample of workers examined, and to apply more correctly the incidence rates of any pulmonary affections disclosed by the examination of the sample (30).

The sample examined (after eleven cases are excluded of fibrosis and prefibrotic conditions due to causes other than the inhalation of asbestos dust) numbered 363, representing 16.5 per cent. of the population at risk, estimated as above. The manner of selection of the sample must be referred to, since just interpretation of the results depends upon a due appreciation of the relationship of the sample to the whole population at risk.

The principle of selecting primarily those longest employed was adopted; but regard was also paid to the other end of the scale, so as to obtain information as to the length of exposure to dust necessary before effects are manifested, and also as to the particular process in which the worker was engaged. It was felt that, in this way, the maximum information would be obtained in the shortest time.

Table 2 shows the distribution, according to length of employment (not necessarily in one factory), of

TABLE 2.—DISTRIBUTION, ACCORDING TO LENGTH OF EMPLOYMENT, OF (A) 775 WORKERS ENGAGED IN ASBESTOS PROCESSES AND (B) SELECTED SAMPLE OF 363 WORKERS

YRS. EMPLOYED	(A)		(B)	
	NO.	PER CENT.	NO.	PER CENT.
0–4	483	62.3	89	24.5
5–9	200	25.8	141	38.8
10–14	51	6.6	84	23.2
15–19	24	3.1	28	7.7
20 and over	17	2.2	21	5.8
Total	775	100.0	363	100.0

775 workers engaged in the processes under review, and of the sample of 363 workers, distributed in the same way. The enormous preponderance numerically of workers employed under five years in these processes is striking, as is also the very low percentage of workers employed ten years or longer.

Comparison of the two parts of the table shows that the effect of this method of selection is that the number examined in each succeeding five-year employment group is a progressively greater proportion of the total number which *could* have been examined in each particular group. With a solitary exception, all those examined were at work on the day of examination.

Not only the value, but the necessity, of radiographic examinations of the chest in investigations into the effects of dust upon the lungs, has been emphasized repeatedly by Watkins-Pitchford, and reaffirmed by the Departmental Committee on Compensation for Silicosis (17). A high standard of radiography is essential; as Watkins-Pitchford phrases it, the radiograms must be "technically satisfactory." Indifferent films are useless, since it is the fine detail of the lung which is being studied.

In a general inquiry, such as this, which involves the examination of workers in factories, large and small, scattered over the country, it is not practicable, nor is it necessary, considering the special purposes of the inquiry, for radiograms to be taken of all the workers examined. The dislocation of work in a factory, caused by the absence of a number of hands for this purpose, cannot be viewed with unconcern, especially when, as is not infrequent, the factory is remote from a center which is equipped with the necessary X-ray plant, and where the services of a consultant versed in the science of radiography of the lungs are available. Furthermore, it must not be overlooked that such examinations are voluntary, and not, as in South Africa, compulsory. Moreover, repeated and protracted examinations only result in the exhaustion of all concerned, and much depends on the willing co-operation of employers and employees, since the only incentive is a desire to further the common welfare.

Radiography, therefore, has a different function in these inquiries, than when it is applied to individual cases for compensation or other legal purposes. This function is not that of replacing careful clinical examinations, as has been recently foreshadowed (18, p. 40), but primarily that of being an indispensable aid in diagnosis, especially of doubtful cases, in the determination of complicating lesions, in measuring the extent and progress of the disease, in locating the point at which the earliest radiographic signs appear, and finally as a check upon the human factor presented by the examiner himself.

The examinations (except one) were carried out at each factory, in a room set apart for the purpose, suitably warmed, and with the necessary appointments. On occasions the noise of traffic or from the adjoining factory was a hindrance, but in one way or another these difficulties were overcome or minimized.

All the selected workers were examined by the writer. At three factories, however, a number of workers were examined jointly with Dr. E. L. Middleton. His far-reaching experience of the

pathologic changes in the lungs, produced by the inhalation of various dusts, was of great value, and his assistance was much appreciated.

Every effort was made to complete the clinical examination of the workers before the onset of winter introduced difficulties due to ephemeral bronchitis, colds, and influenza, which would tend to obscure the main issues. Thus the clinical, and two-thirds of the radiographic examinations were completed by the middle of November, 1928, prior to the commencement of the influenza epidemic early in 1929.

Clinical Examination

Percussion

The inhalation of asbestos dust originates changes in the lungs, which may be looked upon as a measure of the efforts of the living tissues to repel, or incarcerate, the irritant particles of dust. These changes modify the percussion note. It is true that the note elicited may be similar on both sides, but the note is not normal. It is thinner and higher pitched than normal, and there is a sense of resistance imparted to the plexor finger. In other words there is a diffuse, but slight, impairment of resonance.

This alteration in the percussion note, however, is more difficult to recognize because it is bilateral, and extends over a wide area; consequently the aid of contrast percussion is denied. It is best elicited by rapidly, and very lightly, percussing the back of the chest from apex to base on each side. It will be found that the extreme apexes remain clear, but below the apexes the impairment is general. It increases over the root areas; below these, it diminishes in intensity, but still persists. In other words, we find tacked on to the paravertebral dulness an area, above and below, of impaired resonance, which is much more extensive than that usually associated with old inactive hilar tuberculosis.

Impairment of the percussion note was found to be constantly more marked in the right side; in fact, at first it was thought that in the earliest degrees of fibrosis it was confined to that side, but later, and more extended observations lead to the conclusion that the earliest detectable cases are bilateral, although the signs on the left side are tenuous.

This change is so constant that it has been adopted as the most reliable single clinical sign presented by this type of pulmonary fibrosis, and no case has been classified as fibrotic in its absence.

Considering the frequency with which signs indicating what may be termed "enlarged roots" were found in asbestos workers, it may be that paravertebral dulness is one of the earliest signs produced by the inhalation of asbestos dust, indicating congestive changes in the root areas and a choking of the lymphatics with dust. Reflex impairment of note, due to irritation of the lung tissue by dust, is, however, an attractive explanation. It does not follow, of course, that workers presenting these signs will ever develop a definite asbestos fibrosis.

Clearly, the physical signs presented by any case of diffuse pulmonary fibrosis not only may be modified by changes produced by some intercurrent lung disease, but, *ab initio*, will vary according to the state of the lungs before the onset of the fibrosis. Thus,

the fibrosis may be implanted upon a perfectly normal chest, in which case the problem of diagnosis is straightforward. In other cases, however, preexisting root changes, so common in an industrial community, may be present, or the lungs may be already the seat of emphysema and chronic bronchitis, or of definite old tuberculous lesions, or there may be a massive pleural thickening, the result of an old pleural effusion. All these examples have been noted in the present investigation, and others will readily come to mind.

Although in most of these cases the dust fibrosis, if moderate in degree, can be confidently diagnosed, especially with the aid of radiography, it must be admitted that the problem becomes very difficult when the dust fibrosis is comparatively slight, and the changes produced by other conditions are pronounced and diffuse. Three types of these cases have caused most difficulty among those examined; fortunately, numerically they were few.

The first of these is where the dust fibrosis has been implanted upon lungs already emphysematous. It seems that, at any rate in the case of the asbestos fibrosis, until the fibrotic changes get the upper hand, clinical diagnosis of the fibrosis in these cases is impossible. Nevertheless, although the problem of the diagnosis of a fibrosis implanted upon an emphysematous chest has caused some difficulty in this inquiry, it seems likely that it can arise only under exceptional circumstances.

The second type of case which has been a source of difficulty in clinical diagnosis is that in which there are extensive bilateral fibrotic changes due to healed tuberculosis. That there is an extensive fibrosis is clear enough, and that most of it is not due to asbestos is strongly suggested when examination of the lower portions of the lungs shows that they are comparatively slightly affected. Further help in these cases, of course, may be obtained from the history and symptoms.

The third type, also rare, is that in which changes following an old massive pleural effusion on one side so obscure the physical signs of any dust fibrosis as to render that side useless clinically for diagnostic purposes. If the side affected by the pleurisy happens to be the right, the radiographic picture is also curtailed by the normal partial obscuration of the left lung base by the heart shadow.

These three types were, with the possible exception of the first, uncommon, and are mentioned merely to call to mind some of the ways in which an asbestos fibrosis may be masked, in greater or less degree, by changes due to other disease.

Only passing reference need be made to the other physical signs found in the asbestos fibrosis, since they do not differ materially from those presented by silicosis. Chest expansion is diminished and may be reduced to one-half inch or even less in advanced cases. Retraction of the apexes is common, and sometimes shows a peculiar feature differentiating it from that found in fibroid phthisis. Instead of the immobile and sunken apexes seen in the latter disease, the apexes are seen to descend during inspiration, and to rise again during expiration. This seems to indicate the anchoring of normal apexes by fibrous tissue in the lower portions of the lungs. Some confir-

mation of this was obtained radiologically.

Auscultation

In the majority of the cases of fibrosis, the respiratory murmur is weakened, much or little, generally, more on the right side, and often still more at the base; the expiratory sound is weaker than the inspiratory, and often becomes less and less audible as one approaches the bases.

Transitional phases between this and harshened breath sounds and prolonged expiration are not uncommon, even in the same chest. The latter may be noticeable in the upper portions of the lungs, but progressively diminish toward the bases. Other combinations were also noted, however.

The dry character of this type of fibrosis during most of its course is rather striking. Scattered fine râles and clicks in the root areas, axillae, and bases were not infrequent; slight edema of the lower halves of the lungs was noted in one of the more advanced cases; but in a number, no adventitious sounds at all were heard.

Pleural crepitations, and rarely a slight pleural rub, were noted—these attacks seem to cause little pain—and in one case a little fluid at the right base.

No doubt this variability in the sounds heard on auscultation reflects underlying changes, temporary or permanent, in the lung, and is dependent, *inter alia*, on the extent of the fibrosis with its associated pleural thickening—changes due to past disease, catarrh, or other intercurrent affection, and to the degree of compensatory emphysema present.

Symptoms

The symptoms exhibited by these cases of fibrosis, as might be expected, closely resemble those of silicosis. The distribution of the main symptoms, and of one sign, cyanosis, which is included with the symptoms for convenience, is given in Table 3. A few cases have been excluded on the grounds that one or other of the symptoms complained of might be assigned to causes other than the fibrosis, such as a complaint of shortness of breath in a case with a past history of mild thyroid intoxication, or of dyspnea associated with obesity.

TABLE 3.—DISTRIBUTION OF FOUR COMMON SYMPTOMS, AND OF CYANOSIS, AMONG CASES OF FIBROSIS

SYMPTOM	NO. EXAMINED[1]	CASES IN WHICH SYMPTOM WAS PRESENT	
		No.	Per Cent.
Cough	91	54	59.3
Cyanosis	93	52	55.9
Dyspnea	91	47	51.6
Expectoration	91	31	34.1
Pain	94	10	10.6

[1] Excluding those in which the presence of the symptom is referred to other causes.

Between 50 and 60 per cent. of the cases complained of cough, or of shortness of breath on slight exertion, or showed some degree of cyanosis, whereas only about one-third complained of expectoration, and one-tenth of pain, or discomfort, in the chest. Also, while 14.6 per cent. of the cases had no complaints and showed no cyanosis, and only 3.4 per

cent. presented all four complaints and were cyanosed, 60.6 per cent. presented two, three, or four of the five items.

Clearly, none of the four complaints, or the presence of cyanosis, can be an infallible indication of the existence of fibrosis; but the presence of two of them, shortness of breath on slight exertion, and cyanosis in some degree, in an asbestos worker, is highly suggestive, in the absence of other evident cause.

Nevertheless an advanced degree of fibrosis may be present, and little complaint made. Symptoms, unless distressing, are so often a function of the introspectiveness of the patient. Slight degrees of fibrosis, too, give rise to no symptoms, in the absence of an intercurrent bronchitis, since the remaining sound lung tissue is still amply sufficient for all purposes.

Cough was the most frequent symptom, and was of two types. For a few weeks after commencing work in a dusty process, asbestos workers often find the dust irritating, and cough while in the dusty atmosphere; this lasts for a few weeks, and then usually disappears. The writer has noticed this effect on himself, but only while in a very heavy cloud of asbestos dust. The dust seems to be only slightly irritant in this way. One or two men who had previously worked in cotton card rooms, or blow rooms, and were affected by that dust, stated that they were unaffected by asbestos dust. Certainly asbestos dust does not cause asthmatic attacks like those seen in cotton card room workers. One man, who migrated from a cotton card room ("hard waste") nine years ago to an asbestos card room, on account of the irritating effect of the dust, does not find asbestos dust irritating, but to this day cannot work with a cotton scutcher (as he occasionally does) without precipitating a coughing attack within an hour or two. Although he suffers from winter cough and some shortness of breath, he stated that his health has been much better since the change.

Asbestos dust, therefore, has only very mild powers as a reflex irritant of the upper respiratory tract, and is, in this respect, comparable to free silica. This is an unfortunate attribute, since it leads to the assumption that the dust is more or less innocuous.

The second type of cough is more intimately associated with the development of fibrosis, and occurs, or perhaps is noticed, after a varying number of years' work. Usually it is present only in the morning on getting up, when after rather a sharp attack of coughing, a little viscid sputum "like an oyster" is brought up. A similar bout may occur at night after ceasing work; at times it is sufficiently sharp to cause retching. It is generally rather worse in winter, and may be noticed only then. Although it closely resembles smokers' cough, its features are precisely the same in nonsmokers.

Persons giving a history of cough dating from an attack of pneumonia or other illness in childhood, almost invariably state that the cough has not become worse since working with asbestos. One worker succinctly described the cough as "first in the throat; later catches the chest."

Generally, this cough causes very little inconvenience and may pass unnoticed until the development of some other symptom directs attention to the general state of health. Thus, out of

sixty-six cases of fibrosis, in thirty-three (50 per cent.) the cough was stated to have preceded the onset of shortness of breath, in twelve (18.2 per cent.) to have developed contemporaneously, and in twenty-one (31.8 per cent.) was either not noticed until after the onset of shortness of breath, or, although the latter was complained of, cough was not admitted.

Complaints such as "colds go to the chest," and "frequent colds on the chest," were not uncommon. Complaint of spitting of blood was exceptional; and in all cases in which this complaint was mentioned, the exciting cause was, primarily, some disease other than the fibrosis—*e.g.*, in one, it was due to pulmonary tuberculosis; in another, it occurred only during a prolonged attack of pleurisy; and in a third, the hemorrhage was gastric in origin. Cyanosis, a valuable sign when present, rarely amounts to more than a duskiness, or slight blueness, of the lips; it contrasts, however, with the general pallor of the face with which it is often associated in these cases. Cyanosis in some degree was noted in 56 per cent. of the cases. It may be absent even when there is a considerable degree of fibrosis, or it may come and go.

Pain in the chest is rarely complained of, and then it is usually described as "tightness of the chest," "soreness," or "aching." It was noted in 10.6 per cent. of the cases.

Well-marked clubbing of the fingers was noted in a few cases. The general nutrition is hardly affected, except in the latest stages. Only ten (10.5 per cent.) were noted as being thin. In one, the nutrition was very poor; in twenty-one (22.1 per cent.), fair; and in the remainder of the cases, good.

Radiography

Radiograms of the chest were obtained of 133 workers, or 35.5 per cent. of the number examined clinically. Of these, over 100 were taken by Dr. E. W. Twining of Manchester, and Dr. N. Tattersall of Leeds, and the remainder (except one) by Dr. F. L. Henderson of Glasgow. To all three, I am much indebted. Dr. Twining and Dr. Tattersall have devoted many hours to the joint study with the writer of the radiograms, and have drawn freely on their wide experience of radiography of the chest in furthering the purpose of the investigation.

Dr. R. S. Paterson of Manchester, too, added his experience to a final review of the films, and Dr. E. Barclay, now of Cambridge, lent his assistance in interpreting some difficult films; to both, grateful acknowledgment is made.

The standard of radiography was very high; indeed, a high standard is indispensable, if it is desired to trace the cause of such a fine and diffuse fibrosis as that produced by asbestos.

The films are superficially, but only superficially, comparable to silicosis. In the earliest negatives studied with Dr. Tattersall, a characteristic slight obscuration of the lung fields, a general lack of translucency, was noted. This appearance, for want of a better term, was denominated as "veiling." Dr. Burton Wood has independently noted (19) and confirmed this, referring to it as the "ground glass appearance." Dr. Tattersall also drew attention to the more or less rounded "whorls" of

varying size seen in the striation in the mid-zones in some of the films.

There was general agreement as to the fine and delicate nature of the characteristic mottling. Dr. Twining (in a personal communication dated Aug. 2, 1929)—while lamenting that there has been, as yet, neither time nor opportunity to study the changes from every aspect, and therefore his present views may be modified on consideration of all the evidence—states:

> In general my opinion is that the earliest stages are not characteristic radiologically, but that the stage of fine dusty stippling is almost certain to be eventually provable as an early asbestos lesion. We saw it constantly in a large series of films, and after a little experience it is quite easy to detect it.
>
> Some of the other cases showed a few grouped lesions, like rosettes or leopard markings, each component being about the size of a primary lobule. These are similar to lesions sometimes seen in tuberculosis. In the asbestos cases I regard them as being groups of primary lobules making up a lobule, the walls of which are infiltrated. They certainly seem to correspond in size with the macroscopic lesions seen in the pathological specimen.
>
> The advanced cases show heavy basal and mid-field mottlings, common in pneumonoconiosis, with a tendency to avoid the apices.
>
> On the whole the lesions are distinctly less dense than those of silicosis, and are less easy to group into well-defined stages, but I think we can recognise:
>
> 1. A very doubtful stage of increased linear striations.
> 2. Fairly definite fine dusty stippled appearance.
> 3. Coarser mottling with increased linear striations.
> 4. Gross lesions with pleural changes and displacements due to the pull of the fibrosing lesions.
>
> The few tuberculous lesions we have come across have been easily distinguishable.

The radiographic appearances in the earlier stages are most marked on the right side at the base or in the central zone. This corresponds with the clinical findings. This preference for the right side has been noted also in silicosis, by the South African observers. The cases showing radiographic signs of a dust fibrosis have been classified in three broad groups. This grouping, although unscientific, is convenient practically, considering the main purpose of this investigation. Indeed more precise classification based on the particular radiographic changes noted might well be misleading at the present time.

Much combined clinical, radiologic, and pathologic study is required into the whole subject of these fine types of dust fibrosis, which have been noted in workers exposed not only to silicate dusts other than asbestos, but also to other inorganic dusts containing no silica, before it will be possible to classify the radiologic changes as has been done so successfully by the South African workers in respect to silicotic fibrosis.

The hypothesis that, because asbestos dust produces a pulmonary fibrosis with consequent deviations from the normal in the lung skiagram, the degree and potentialities of this fibrosis can be assessed by comparison of its radiologic picture with those of standard silicotic films, is untenable.

At least two general types of pulmonary fibrosis caused by inorganic dusts can be recognized. A third, representing the purely peribronchial variety of fibrosis, might be added; or it may be that all dust fibrosis will be found to approximate more or less closely one or the other of these two

types. These types are (1) that produced by combined silica dust, an example of which is seen in asbestos fibrosis, and (2) that produced by free silica dust, represented by silicotic fibrosis.

These two types, while resembling one another in clinical signs and symptoms, differ materially both in the nature of the lesion produced in the lung, and in the character of the associated radiographic picture. Thus, attempts to weigh, consciously or unconsciously, asbestos fibrosis, or any dust fibrosis other than silicosis, by means of the standard radiographic changes found in silicosis, is unsound and is likely to lead to a misconception of the potentialities of the dust in question.

Badham (8) gives an example of this source of error in reporting the unexpectedly early death of a man affected with a fine fibrosis caused by an orthoclase basalt containing no free silica. Referring to some of the radiologic differences between the fine fibrosis of dusts other than silica and the nodular fibrosis of quartz dust (*i.e.*, true silicosis), he states:

> Moreover, the coarse fibrosis of silica gave clear interspaces of normal lung, while the fine fibrosis presented a uniform granular mottling leading to the conclusion which is probably erroneous that the actual development of fibrous tissue was greater in a nodular fibrosis as silicosis than in a generalised fine fibrosis caused by silicates. To me it appears that the mechanical damage to the lung is greater in a fine fibrosis than in a coarse fibrosis when both are well developed.

The evidence obtained in the present inquiry amply confirms this general statement.

On studying the development of asbestos fibrosis as displayed in a series of radiograms, and especially in the few available taken a year or more before a fatal termination, one cannot help asking the question, "What is there here which could have this effect?" The answer is that the damage to the lung is much greater than it appears to be when judged by the silicotic standard. Asbestos fibrosis is much more diffuse; it spins its fine web, as it were, crisscross throughout the lung, enveloping and eventually strangling the ultimate lobular structure, rather than depositing itself in numerous more or less isolated foci, as in silicosis. Thus, at any rate in the less advanced stages, the radiologic picture of the lesions does not impress the eye, unconsciously viewing it from the standpoint of silicosis.

The radiographic picture may show soft and fairly coarse nodulation, but it is never so impressive as the nodulation in a silicotic film.

Paradoxically, the distinctive feature, both clinically and radiologically, of the asbestos fibrosis is its uniformity. The modesty of the symptoms; the unobtrusive, but diffuse, impairment of the percussion note; the homogeneous stippling of the skiagram; all are fragments of an entity, unmistakable when assembled, but enigmatic when divorced.

Only two references to the radiographic appearances of the chest in asbestos workers have been traced: one in a report by Pancoast and Pendergrass (10), and the other in an article by Burton Wood (19).

Pancoast and Pendergrass together with Miller and Landis examined "17 asbestos workers, 2 of whom showed

first stage changes and the other 15 definite second stage appearances. Of the men longest at work, one after seventeen years' occupation showed very definite diffuse, 'soft' spots throughout both lungs, and another showed about the same appearance after fourteen years' occupation. Very slight nodular shadows were found in one man after only two years' occupation. Most of these second stage cases showed also well-marked first stage appearances still present, indicating a persistence of free drainage hilumward. In all instances the nodular shadows were characteristically 'soft' and varied considerably in size." Their first stage appears to correspond with stage 1, and their second stage with stages 2 and 3 mentioned above.

It appears from the context that these observers regard asbestos fibrosis as being really a silicosis due to admixture of free silica derived from the original rock—a view difficult to substantiate.

Burton Wood (19) in a series of fifteen skiagrams of asbestos workers notes: "The most noticeable feature of skiagrams of workers exposed longest to asbestos dust is the presence of shadows suggesting a diffuse fibrosis affecting chiefly the lower two-thirds of the lungs. The fine quality of the shadows is worthy of note. Some of the cases exhibit a 'ground glass' appearance, though on close inspection fine mottling is evident. . . . when more definite mottling is present it lacks the coarse quality described in the skiagrams of chests showing pneumoconiosis, e.g. South African gold miners. . . . . "

Clearly, the maturation of asbestos fibrosis is spread over a period of years, and by the time the stage is reached when the features discussed above are, in varying degree, positive, and the radiologic picture is recognizable, the fibrosis is not in its inception, nor even in its earliest stages, but is developed and fairly widespread.

We must, therefore, recognize an earlier state when the fibrosis is present in slight degree, and also when there is evidence of choking of the lymphatics, and of a measure of pulmonary catarrh. This stage may be referred to conveniently as the prefibrotic stage.

The indications of this stage are indefinite, and some, at any rate, not specific. If, however, they can be determined and applied with only a moderate degree of accuracy, information of practical value will be available. Efforts have been made, therefore, to distinguish workers in this stage. The following tabulation shows that twenty-one workers out of 363 examined (5.8 per cent.) were so classified:

Clinical Examinations (363):	*No.*	*Per Cent.*
Fibrosis	95	26.2
Prefibrotic conditions	21	5.8
Radiologic Examinations (133):		
Fibrosis	52	39.1
Suggestive changes not definitely diffuse fibrosis	22	16.5

Many of these cases present a slight diffuse impairment of percussion note —perhaps better described as a slightly increased sense of resistance felt on percussion, mostly of the right lung, at least as contrasted with the left, and associated with some weakening of the respiratory murmur. Probably this early stage could be detected radiographically, but only by means of

comparison with a radiogram taken prior to commencing work with asbestos. By such means the earliest stages of silicosis have been worked out by the South African observers. There, the radiograms taken at periodic six-monthly medical examinations can always be compared with initial radiograms taken before the employees are permitted to work underground. group is dismissed from any further consideration.

A general summary of the findings in the 374 workers who were examined clinically, classified under the most important lesion, is presented in Table 4.

Illustrative Cases

The salient points of a few cases are set out below to illustrate clinical and

TABLE 4.—GENERAL SUMMARY OF FINDINGS CLASSIFIED UNDER THE MOST IMPORTANT LESION

YRS. EMPLOYED	NO. EXAMINED	CASES OF FIBROSIS		PRE-FIBROTIC CONDITIONS		PULMONARY TUBERCULOSIS			CASES OF OLD HILAR TUBERCULOSIS, OR SUGGESTING ENLARGEMENT OR CONGESTION OF LUNG ROOTS	PULMONARY AND BRONCHIAL CATARRH, AND BRONCHITIS	OTHER PULMONARY LESIONS			WITHIN NORMAL LIMITS
		Due to Asbestos	Due to Other Causes	Due to Asbestos	Due to Other Causes	With Evidence of a Dust Fibrosis	Other Active Lesions	Other Inactive Lesions			Pleurisy[1]	Emphysema[2]	Other Lesions	
0–4	92	0	3	5	0	0	0	0	13	7	1	0	1	62
5–9	142	36	1	12	0	1	1	4	3	3	5	2	2	72
10–14	89	27	5	3	0	3	0	3	5	0	3	2	0	38
15–19	30	15	1	1	1	0	0	1	0	2	1	1	0	7
20 and over	21	17	0	0	0	1	0	0	0	1	0	1	0	1
Total	374	95	10	21	1	5	1	8	21	13	10	6	3	180
Percentage	100	25.4	2.7	5.6	0.3	1.3	0.3	2.1	5.6	3.5	2.7	1.6	0.8	48.1

[1] One case of thickened pleura due to old gunshot wound.
[2] One case of emphysema due to gassing.

In other cases included in this group, diffuse weakening of the respiratory murmur was noted, with fine sticky râles in the root areas. At present no stress can be laid upon this group. The clinical changes are so slightly marked that until comparative radiograms are available it would be unsafe to draw any deductions. For the purposes of this inquiry, therefore, this other features. Five radiograms are reproduced to illustrate the radiologic appearances of some of the cases. There are insuperable difficulties, however, in reproducing the finer changes depicted in the original negatives.

Case 1.—This worker, a female, aged 24, has been employed in asbestos for ten and one-half years—as a card tenter one year,

and as a doubler nine and one-half years. Her family and personal medical history contain nothing of note. She has no complaints and feels quite well. Her nutrition is good. She is pale, but shows no cyanosis.

Chest.—She has a chest expansion of 1¼ inches. No impairment of the percussion note is detected. The breath sounds in the right lung are weaker, generally, than those in the left. Expiration is prolonged at the right root; no added sounds are heard. A skiagram showed some very slight and doubtful changes in the direction of increased striation.

Case 2.—This man, aged 24, has been employed in asbestos for five years, carding and mixing. Previously he worked for four years in the cotton trade, yarn weighing. His family and personal medical history contain nothing of note. He has had a slight morning cough and expectoration for a year. His nutrition is good. His color is fresh, and there is no cyanosis.

Chest.—There is some impairment of the percussion note over the middle third of the right lung, behind, and slightly at the right base. The breath sounds are harsh, and expiration is prolonged in the upper half of the right lung, behind; expiration is also prolonged over the left upper lobe, behind. The respiratory murmur is weakened at the right base, and the breath sounds are of a "whiffing" character. There are no added sounds. A skiagram showed enlargement of the right root, and slight haziness and striation in the central zones in both lungs, suggesting early fibrosis.

Case 3.—This man, aged 32, has been employed in asbestos for six years in the card room, and as a stripper and grinder. Previously he was employed in a cotton card room for nine years. He had army service for five years, but was not gassed. He gives a family history of asthma; otherwise there is nothing of note in his family or personal medical history. He has no complaints and feels quite well. His musculature is very good. His color is pale, but he shows no cyanosis.

Chest.—There is slight impairment of the percussion note generally, particularly at the right base. The respiratory murmur is a little weakened generally. No added sounds are detected. A skiagram showed old tuberculosis of the lung roots and general increased striation, especially in the lower half of the right lung, suggesting early fibrosis.

Case 4.—This worker, a male, aged 23, has been employed in asbestos for nine years, mostly mattress making. His family and personal medical history contain nothing of note. He complains of occasional pain in both sides of the chest, and perhaps a little undue shortness of breath on exertion. His color is normal. His musculature and nutrition are good.

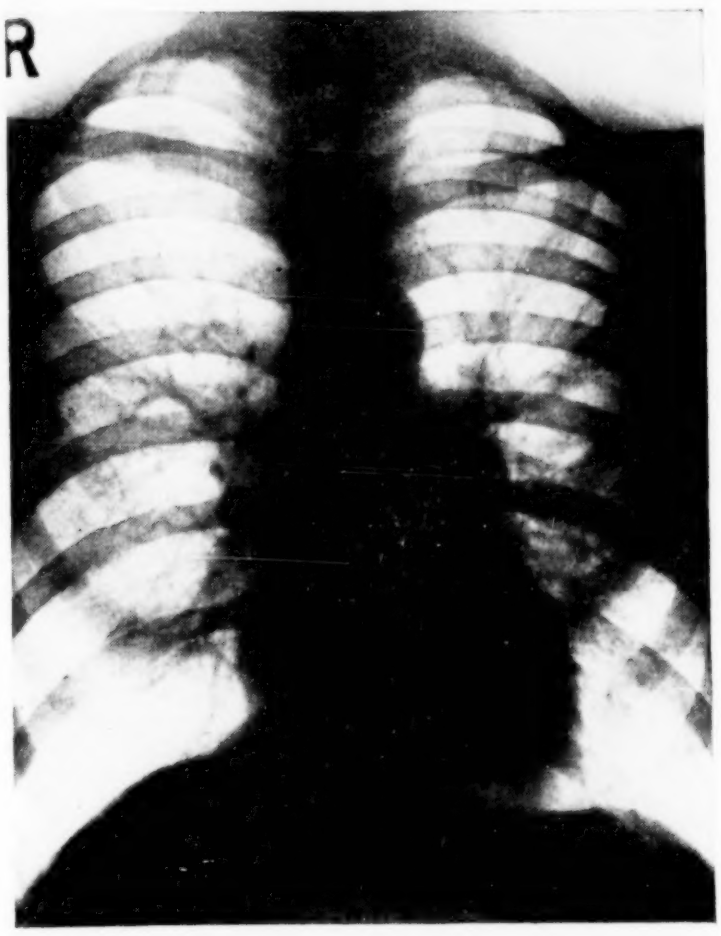

Fig. 1.—Case 4: Moderate fibrosis. Undue degree of striation and fine mottling in central zones of both lungs; calcified glands in roots, with rather coarse striation in upper lobes; ? interlobar pleurisy on right side, between the lower and middle lobes; emphysema at bases.

Chest.—There is no retraction of the apexes, but there is a slight flattening below the right clavicle. The percussion note is slightly impaired generally, behind, particularly on the right side. The breath sounds are weak, generally, and expiration is prolonged. No added sounds are detected. The skiagram (Fig. 1) shows an undue degree of striation and fine mottling in the central zones of both lungs; calcified glands in the roots, with rather coarse striation in

the upper lobes; ? interlobar pleurisy on the right side, between the lower and middle lobes; and emphysema at the bases. The case was diagnosed as moderate fibrosis.

Case 5.—This woman, aged 40, has been employed for eleven years in asbestos, for most of the period mattress making. Previously she was employed in a laundry. She has recently been ill for three months with pleurisy (no history of tapping); otherwise her family and personal medical history

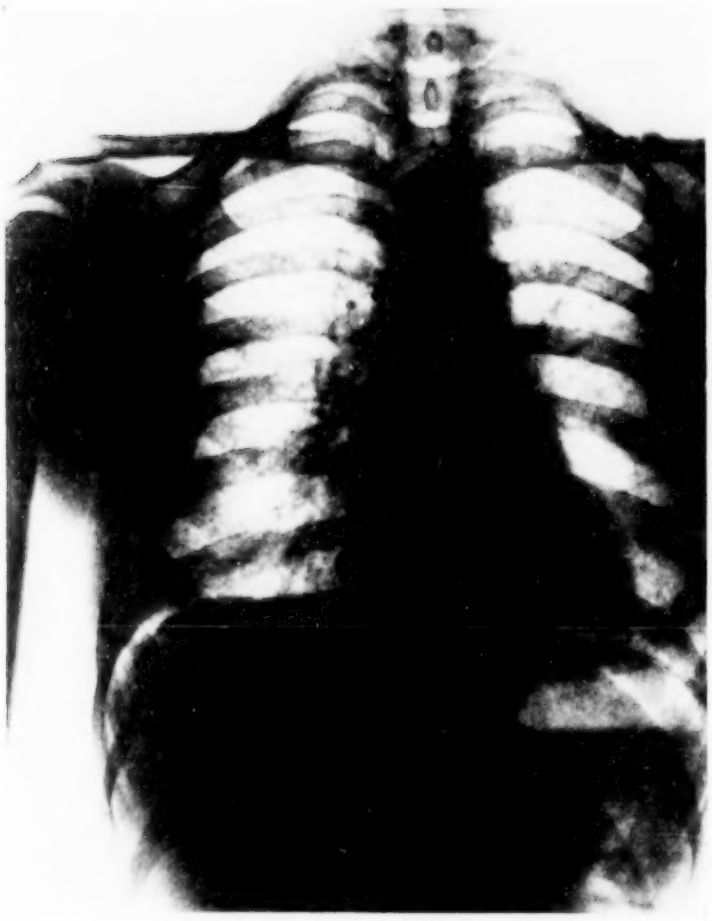

Fig. 2.—Case 6: Moderate, but fully developed, fibrosis. Enlarged glands in both roots; diffuse fine mottling in both lungs, especially the right.

are negative. She complains of having had a winter cough for three or four years, and of shortness of breath on exertion since her attack of pleurisy. Her nutrition is good; her weight is stationary. She has normal color, and no cyanosis.

Chest.—There is some general impairment of the percussion note over both lungs, behind, more noticeable at the bases. The respiratory murmur is weakened generally. Persistent crepitations and medium râles are noted low down in the right axilla. A skiagram showed diffuse fine striation and fine nodular mottling, with light opacity at the bases. The case was diagnosed as moderate fibrosis, most marked toward the bases.

Case 6.—This worker, a female, aged 31, has been employed in asbestos for seven years, opening, and has been exposed to much dust. Her previous employment was non-dusty. Her family and personal history disclose nothing of note. She complains of having had a cough for five years, and of shortness of breath on hurrying. She is thin and undernourished, and pale.

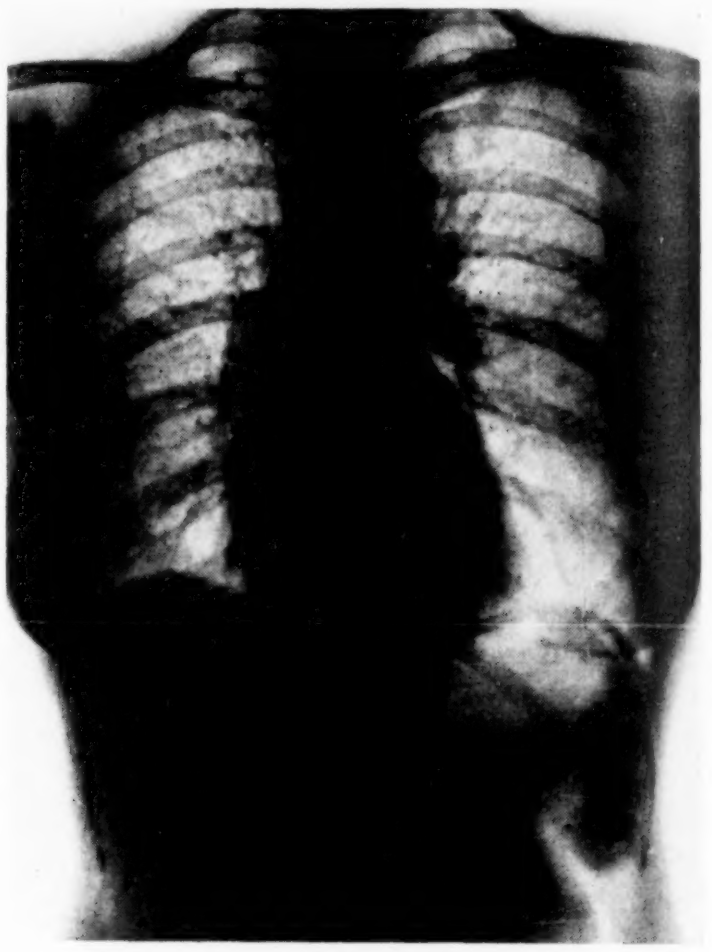

Fig. 3.—Case 7: General fibrosis, mostly linear, but with little mottling of right lung. Old puerile tuberculous scars at apexes.

Dust is present on her hair and in her nostrils.

Chest.—She has a chest expansion of one-fourth inch. There is slight general impairment of the percussion note, definite at the apexes and the bases. The breath sounds are weak; expiration is slightly prolonged. No added sounds are heard. Her heart is not enlarged, and no murmurs are detected. The skiagram (Fig. 2) shows a number of enlarged glands in both roots, and a diffuse fine mottling in both lungs, especially the right. This is a case of moderate, but fully developed, fibrosis.

Case 7.—This woman, aged 48, has been

employed in asbestos for thirty-two years—about three years on cards, and the remainder as a spinner. She has done no other factory work. Her family medical history discloses nothing of note. She has a personal history of nephritis seven or eight years ago, causing three months' illness. Her complaints are: shortness of breath on hills, and winter cough for about six years. Her nutrition is fair. She is rather pale.

Chest.—She has a chest expansion of one-half inch. No retraction of the apexes is noted. There is general slight impairment of the percussion note, behind. Breath sounds are harsh and expiration is prolonged. No added sounds are heard. No gross enlargement of the heart is noted, but the second sound is found to be accentuated over the aortic area. The skiagram (Fig. 3) shows a general fibrosis, mostly linear, but with a little mottling of the right lung. There are also very old puerile tuberculous scars at the apexes. The case was diagnosed as general fibrosis.

This case should be compared with Case 6. In Case 6 there was a heavy exposure to dust extending over a few years; in the present case there was exposure to a very much less concentration of dust, except possibly in the first three years, but extending over many years.

Case 8.—This worker, a male, aged 62, has been employed in asbestos for twenty years as a weaver. He was previously a cotton and silk weaver. His family and personal medical history show nothing of note, except that he was regarded as a delicate child. His complaints are: shortness of breath on exertion, and on going upstairs, for three years; morning cough and a little expectoration for the last three winters. He is thin and pale, with some cyanosis.

Chest.—Chest expansion is 1 inch; there is retraction of the apexes. The percussion note is impaired over both upper lobes, in front, and over the upper two-thirds of the right lung, behind. Expiration is prolonged at the bases. Pleural rub and inconstant râles are noted at the left base, and a few râles at the right base. A skiagram showed a definite diffuse fibrosis with nodulation. This is a case of fibrosis in the early advanced stage.

Case 9.—This man, aged 41, has been employed for twenty years in asbestos in many capacities. There is nothing of note in his family history. He gives a history of pneumonia a number of years ago. His complaints are: a little shortness of breath on exertion for the last two or three years; otherwise none. His nutrition is fair only. His color is fresh, but there is slight cyanosis of the lips, at times.

Chest.—The skin is poorly elastic; there is some retraction of the apexes. There is an impaired, rather "boxy," note on percussion, generally, especially over the upper half of the left lung, and over the upper two-thirds of the right lung, behind, and in front. Respiratory murmur is generally weak. Expiration is slightly prolonged, but diminishing toward the bases. Pleural crepitations are noted low down in the right axilla. A skiagram showed a definite fine diffuse fibrosis. Neither lung lights up very well, and throughout both there is a very fine diffuse reticulation and mottling—moderate, but fully developed, fibrosis. The fine diffuse character of the radiologic appearances is particularly noticeable here.

Case 10.—This man, aged 46, has been employed for twenty-five years in asbestos, during nine years of which he was not exposed to dust. For eleven years of the remainder he was employed in the card room, and mattress making. His family and personal medical history disclose nothing of note. His complaints are: shortness of breath on exertion for three months; cough after a few hours' work in dust during the last two or three years, with little or no expectoration; and pain in the left side of the chest for the last three months. His nutrition is good. He is pale, with slight duskiness of the lips.

Chest.—There is some retraction of the apexes. The percussion note generally is impaired, and of a "boxy" character. Breath sounds are harsh and expiration is prolonged over the right upper lobe; elsewhere the respiratory murmur is a little weakened and expiration is not materially prolonged. No added sounds are heard. The heart is normal. The skiagram (Fig. 4) shows diffuse striation and fine speckled mottling throughout both lungs—fibrosis, fully developed.

Case 11.—This worker, a male, aged 40,

has been employed for twenty-two years in asbestos—during the first eleven years on cards and as a weaver, during which he was exposed to a considerable concentration of dust. During the remainder of the time he was employed on a non-dusty process, but was exposed to a less concentration of dust derived from other processes. His family and personal medical history give nothing of note. His complaints are: shortness of breath on climbing stairs for the last five years; slight morning cough and expectoration for about the same time; and slight aching of the chest in front, below the left clavicle. His nutrition is good. There is slight cyanosis of the face.

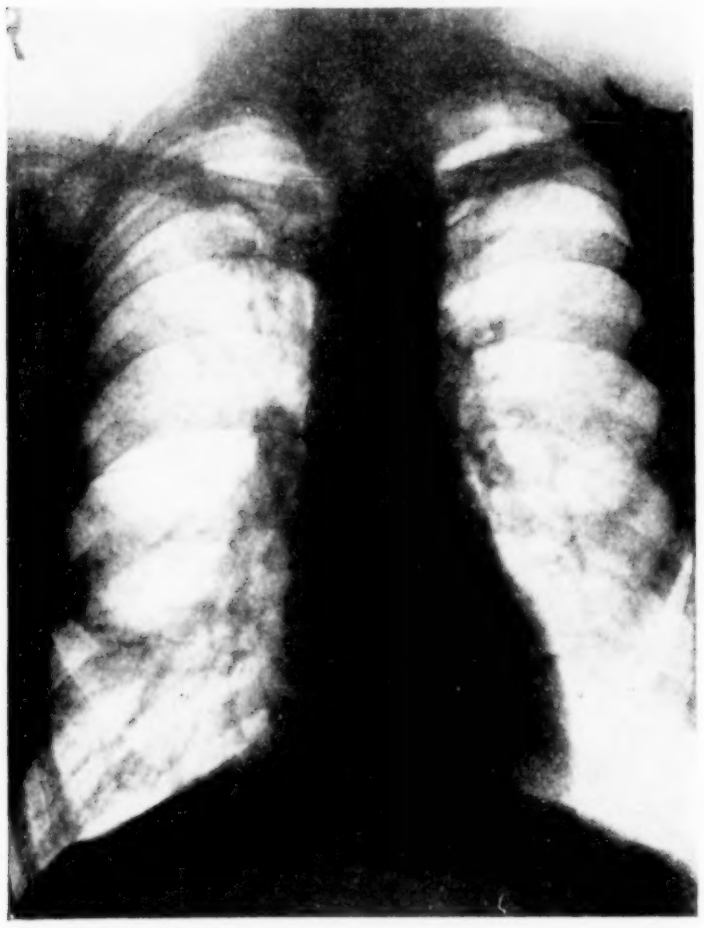

FIG. 4.—Case 10: Fully developed fibrosis. Diffuse striation and fine speckled mottling throughout both lungs.

Chest.—Chest expansion is 1 inch; there is retraction of the apexes. There is impairment of the percussion note generally, most evident over the whole of the right lung, behind, and over the right upper lobe in front. The note is "boxy" over the remainder of the chest. The breath sounds are slightly weakened generally, except at the right apex, but there is no gross change. Expiration is prolonged generally. Fine crepitations are heard in both axillae, and over the right upper lobe, in front. The heart is normal. Sputum is mucoid, but is negative for Bacillus tuberculosis. Clubbing of the fingers has been noted for about two years. A skiagram showed an extensive diffuse fibrosis—fibrosis in a fairly advanced stage.

CASE 12.—This worker, a male, aged 60, has been employed in asbestos for twenty-six years in the card room. Previously he was a sawyer's laborer. There is nothing of note in his family and personal medical history. He complains of slight shortness of breath on exertion of recent years, and of winter cough for the last three or four years; expectoration is stated to be nil. His musculature and nutrition are fair. There is slight cyanosis of the face.

Chest.—He has a chest expansion of three-fourths inch. The percussion note is impaired generally, especially over the left upper lobe in front. The respiratory murmur is weakened over the whole of the chest except the left upper lobe, where there are whistling breath sounds, and medium râles. The heart is normal. A skiagram showed very extensive changes throughout the chest of a coarse type without fine stippling. The roots showed a choked appearance. There was heavy mottling at the base. One old tuberculosis focus was noted at the left base, and some calcified glands in the left hilum. The diagnosis was fibrosis in the advanced stage.

CASE 13.—This man, aged 66, has been employed in asbestos for twenty-one years as a weaver. For about sixteen years previously he was a cotton and silk weaver. His father died of "chest trouble" at the age of 45; his sister died aged 15 of pulmonary tuberculosis. He has only been away sick a week or two in twenty-one years, and has never had any serious illness. His complaints are: undue shortness of breath on exertion during the last two years; cough for the last two or three winters. Expectoration is creamy, and occurs a fair amount of times. He has lost weight, and is thin. He is pale, but with some cyanosis of the face, and with a malar flush.

Chest.—Chest expansion is $1\frac{1}{4}$ inches; there is retraction of both apexes. Dulness is detected on percussion over the upper two-thirds of the right lung and over the left

upper lobe, behind, and over both upper lobes in front. Breath sounds are rather weak, with prolonged expiration. Scattered variable rhonchi and râles are heard over the right lung, behind, over the left upper lobe in front, and over the left root. The skiagram showed a definite diffuse fibrosis plus tuberculosis. Sputum was negative (one examination). The diagnosis was dust fibrosis in the advanced stage, with tuberculosis, probably active.

Case 14.—This worker, a male, aged 36, commenced work in an asbestos plant in 1910, but was employed on other work until January, 1914. During the next five years, until early in 1919, about three years and nine months were spent in army service, for nine months of which he was a prisoner of war, but he had two short periods of work in asbestos—eleven months in the weaving, and six months in the mattress, departments. From early in 1919 to November, 1927, he worked in asbestos processes, but for only six years and ten months in a dusty one (mattress making). He then ceased work. He was referred to a tuberculosis dispensary on Oct. 19, 1927, when he gave a history of bronchitis in 1916 and 1917 during the War, and of never being very well since; complaining of dyspnea, pain in the right side, and a slight cough of only about six months' duration, with a small amount of grayish sputum. Dr. N. Tattersall states that at that time:

"Dyspnoea was very marked, even on talking, and there was definite cyanosis. He had marked hollowing and respiratory retraction at both apices, especially the right; loss of note over most of the right lung and the upper half of the left; bronchial breath sounds at both apices; fairly numerous crepitations, mostly on the right side, and a pleural rub at the right base. He had a systolic bruit at the apex and pleuropericardial friction.

"I examined him a number of times, the last occasion being April 20, 1928. In that time he had lost 9 pounds, felt very weak, and the dyspnoea was increasing. The signs remained much the same, though occasionally, if he got a cold, the moist sounds were more numerous, especially at the bases. Seven sputum examinations were negative, and up to the time I last saw him the sputum had remained small in amount, and its appearance did not suggest tubercle.

"My diagnosis from the beginning was one of pulmonary asbestosis with possibly added tubercle.

"I took two X-rays of him, neither of which showed appearances suggestive of tubercle, everything pointing to a very extreme degree of fibrosis."

He died on Oct. 13, 1928. No postmortem examination was obtained.

Fig. 5.—Case 14: Massive fibrosis, with pleural thickening, retracted apexes, and pneumothorax on left side with incomplete collapse of lung.

It will be noted that the length of exposure to asbestos dust is unlikely to have been more than about ten years and two months, and of this time he was employed only about eight and one-half years in a dusty process. War service, of course, may have reduced his resistance. The skiagram (Fig. 5) shows a massive fibrosis with pleural thickening, retracted apexes, and pneumothorax on the left side with incomplete collapse of the lung.

No doubt fibrosis of the type produced by asbestos dust can of itself lead to complete disablement, and

finally to a fatal termination, even in the absence of a superadded tuberculous infection.

The primary effect of the fibrosis would appear to be that of causing defective aeration of the blood, resulting in an added strain on the heart. For many years, and even with an advanced degree of fibrosis this may be of little inconvenience, provided physical exertion is limited, and acute illnesses are avoided. Ultimately, however, the margin of safety, already diminished, is lost and the circulation slowly fails, with the usual signs of edema of the lungs. More often, however, an attack of bronchopneumonia, influenza, or other acute infection adds too much to the strain, impairs the cardiac musculature, and results in a fatal termination.

(*To be concluded*)

BOOK REVIEWS

BLEIVERGIFTUNG. By Prof. Dr. *Paul Schmidt*, Direktor des Hygienischen Instituts der Universität Halle a. d. S.; Priv.-Doz. Dr. *Adolf Seiser*, Oberassistent am Hygienischen Institut Halle a. d. S.; und Priv.-Doz. Dr. *Stillfried Litzner*, Assistent an der Medizinischen Klinik Halle a. d. S. Paper. Pp. 79 with index, illustrations, and bibliography. Berlin and Vienna: Urban & Schwarzenberg, 1930.

This monograph is divided into a short introductory or general section and a special section. The first part is devoted principally to a discussion of the outstanding diagnostic symptoms of lead poisoning and of the work done by Dr. Schmidt and his collaborators in the microchemical determination of lead in blood, urine, and feces. The second part discusses in detail the usual sources of lead poisoning; the absorption, distribution, and excretion of lead; the pathology and clinical findings associated with lead poisoning; and, finally, the diagnosis, prophylaxis, and therapeutic treatment of lead poisoning.

Dr. Schmidt's monograph is particularly apposite. It brings the literature of the subject down to the present date and represents the mature thought of an investigator who has long made this field particularly his own. The discussion of the diagnostic features of lead poisoning is especially clear and to the point. In this connection it is of interest to note that emphasis is placed on the importance of the determination of lead in the blood.

No attempt is made to discuss the details of technic. The monograph presents instead a critical review of the more recent experimental work relating to lead poisoning and will, in consequence, doubtless have a wide appeal to all investigators in this field. The bibliography, which contains 298 references to the recent work and brings the literature of the subject down to 1930, is particularly valuable. "Bleivergiftung" may well be recommended as a valuable addition to the library of students of public health.—*L. T. Fairhall.*